EARTHJUSTICE

March 15, 2024

VIA FOREST SERVICE OBJECTION PORTAL

Janelle Crocker, Regional Forester
U.S. Forest Service, Alaska Region
709 W. 9th Street
P.O. Box 21628
Juneau, AK 99802-1628

Re: Objection to the Greens Creek Mine North Extension Project Final Environmental Impact Statement and Draft Record of Decision

Dear Regional Forester Crocker:

Pursuant to 36 C.F.R. Part 218, Friends of Admiralty Island (Friends) objects to the Final Supplemental Environmental Impact Statement (2024 FSEIS) and Draft Record of Decision (Draft ROD) for the Greens Creek Mine North Extension Project ("Greens Creek Extension Project" or Project). Friends has a long history of cooperative engagement with the Forest Service on issues related to managing the Admiralty Island National Monument (Monument). However, Friends has significant concerns and objections to the underlying analysis conducted by the U.S. Forest Service (Forest Service) as well as its decision set out in the Draft ROD. As discussed in detail below, the issues raised by Friends in its comment letter on the Draft Supplemental Environmental Impact Statement (2023 DSEIS) have not been adequately addressed.

The Monument was established in 1978 through Proclamation 4611. It was recognized for its unique resources of scientific, cultural, historic, and ecological interest.[1] The Proclamation further states that the spatial boundaries to which the Proclamation applies, including submerged lands, are the smallest area compatible with the proper management of the Monument and protection of its unique characteristics.[2] These boundaries cannot be infringed upon or reduced without having adverse effects to the management of the Monument's values.[3]

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[1] Proclamation 4611, Dec. 1, 1978, 93 Stat. 1446. Two years later, the Monument was recognized in the Alaska National Interest Lands Conservation Act (ANILCA) with the purpose of "protect[ing] objects of ecological, cultural, geological, historical, prehistorical, and scientific interest." *See* 94 Stat. 2400, P.L. 96-487, § 503, Dec. 2, 1980*; see also* 2024 FSEIS, Tbl. 3.19-1, at 3-299 (identifying the numerous resources identified in proclamation or legislation).

[2] Proclamation 4611, Dec. 1, 1978, 93 Stat. 1446.

[3] *Id.*

The Monument's individual values cited for protection include the natural ecology of the island. Ecology stands out among the values because it forms the foundation of all the others. Ecologically, the island is described as a unique, diverse, entire and relatively unspoiled ecosystem. It was set aside 45 years ago because places like this were becoming increasingly rare.

In the intervening years it has become known that intact ecosystems such as the Monument function less like isolated ecosystems and more like a global storehouse of carbon and genetic diversity. The Monument does both and both are necessary to buffer the adverse impacts of climate change. The Monument is of global significance.

The 2024 FSEIS appears to undervalue the reasons the Monument was established. For instance, despite comments by Friends on the DSEIS, the 2024 FSEIS still ignores any value of cultural resources beyond physical objects described in section 2.5.3.[4] The Monument was meant to protect less tangible cultural resources such as food sovereignty and opportunities for cultural practices as described in the Monument Proclamation.

The Greens Creek mine is unique, being completely enclosed within the Monument.[5] Initial discovery of the mineral deposit dates back to 1974. Hecla Greens Creek Mining Company's (Hecla) efforts to operate the mine initiated in the early 1980s. In 1983, the Forest Service prepared the first environmental impact statement (1983 EIS) for the mine and approved the original General Mine Plan of Operations ("Plan of Operations") in 1984.[6] Over the subsequent years, the Plan of Operations has been amended, requiring additional Forest Service approvals.[7]

Among mine plan alterations, Hecla has sought to expand its tailings capacity on three occasions.[8] In 2003, the Forest Service prepared an environmental impact statement (2003 EIS) and authorized expansion of the tailings facility, which would include 15.5 acres within the Monument.[9] In 2010, Hecla sought to expand its tailing area 116 acres into the Monument, resulting in a permanent loss of more than 1,600 feet of salmon stream habitat.[10] In 2013, the Forest Service prepared an environmental impact statement (2013 EIS) and through its 2013 record of decision (2013 ROD), authorized an expansion of the existing tailings facility of only 18 acres into the Monument.[11] As a means of evaluating options that would limit impacts to the Monument, the Forest Service developed an option where a second tailings facility would be

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[4] 2024 FSEIS at 2-47.

[5] *See* A.W. West, *The History of Greens Creek Exploration* (2010).

[6] *See* 2024 FSEIS at S-1.

[7] *Id.*

[8] *Id*. at 2-2.

[9] *See* Forest Service, Greens Creek Tailings Disposal Record of Decision at 6 (Nov. 2003).

[10] *See* Forest Service, Press Release: *U.S. Forest Service issues decision on Greens Creek tailings facility* (Sep. 6, 2013); *see also* Forest Service, Greens Creek Mine Tailings Disposal Facility Expansion Record of Decision at 1, 3, 5-6 (Sept. 2013) (2013 ROD).

[11] *See* 2013 ROD at 1, 6. Hecla sought to expand the tailings pile by 54 acres, all of which would be with the Monument. *Id*. at 5–6.

constructed outside of the Monument.[12] However, the 2013 ROD did not allow construction of the second tailings facility.[13] In making the decision, the Forest Supervisor noted that

> [t]his decision was an unusually difficult one for me to make. In 2003, I made a similar decision to expand the tailings disposal facility, a decision expected to last far longer than 10 years. Thus, the intent of this analysis was to provide a longer-term solution to provide greater certainty to all parties about the future of Greens Creek Mine and of the protection of Admiralty Island National Monument. . . . Knowing how strongly people feel about the issues raised by this project, I concluded there will be time to gather and analyze additional information before authorizing further impacts on the Tributary Creek watershed or a second tailings disposal facility and the associated effects such a facility would have. Thus, while I was hoping to avoid another relatively short-term decision, I have determined that it is the wiser course of action. It allows time to gather and analyze additional information, to thoroughly consider all feasible ways to provide additional tailings disposal capacity, and to clearly and convincingly document such consideration through future NEPA processes.[14]

Expansion has become routine for the Greens Creek mine. In each instance, the Forest Service has considered a range from large to small expansion. In its approval, the agency relies on the fact that the authorized alternative has less impact than other alternatives. For example, the 2013 ROD found that "[t]he total effects of the Selected Alternative are far less than those associated with any of the action alternatives analyzed in the Final EIS, because the Selected Alternative would disturb only one-fifth to one-third of the total acreage affected by any of the action alternatives."[15] Ten years later, as predicted, Hecla seeks to expand once again. Now, the Forest Service is authorizing an expansion that will extend the life of the mine by 12 to 18 years.[16] The other alternatives under review would have extended the life of the mine from 17 to 28, or 27 to 40 years, respectively.[17] In assessing the expansion possibilities, the Forest Service prepared another EIS, supplementing the 2013 EIS, the 2003 EIS, and the 1983 EIS.[18] And once again, the Forest Service has authorized expansion on the grounds that the selected alternative will have less impacts than the other options, as it extends the mine for a shorter period of time.

Considering the currently proposed short-term expansion in light of the statements made by the Forest Supervisor in 2013, it is becoming apparent that the Forest Service will continue to proceed in a piecemeal fashion, allowing for expansion in small increments. With this approach, the Forest Service improperly dismisses long-term impacts when it asserts that the selected alternative appropriately allows for continued operations, while minimizing harm. This approach fails to acknowledge the long-term, cumulative impacts stemming from the now routine mine

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[12] *Id.* at 6.
[13] *Id.*
[14] *Id.* at 9.
[15] *Id.* at 3.
[16] Draft ROD at 4.
[17] 2024 FSEIS at S-3.
[18] *See* 84 Fed. Reg. 64,108, 64,109 (Oct. 9, 2020).

expansions. Further, despite the fact that the Forest Service, and public, can reasonably anticipate the mine will seek additional expansions to continue operating for at least 40 years, the agency has proposed to approve yet another short-term expansion without completing the actions the Forest Supervisor recommended in 2013 to address outstanding overarching questions about the impacts of the mine's expansions. As a result, the Forest Service is failing to meet its obligations under the National Environmental Policy Act (NEPA) and ANILCA.

TABLE OF CONTENTS

DESCRIPTION OF THE OBJECTING PARTY

On May 23, 2023, Friends, the objecting party, submitted substantive comments on the Greens Creek Mine Extension Project and the associated 2023 DSEIS.[19] In addition, Earthjustice, on behalf of Friends, submitted a letter to the Forest Supervisor Frank Sherman in December 2023 further outlining concerns regarding compliance with ANILCA.[20]

Friends was established in 1987, and is an all-volunteer, non-profit organization advocating for the continued protection of Admiralty Island's unique values; and to support Admiralty's role in providing sustainable, wilderness-based, recreational, educational, and economic and cultural opportunities. Friends has been involved in past public actions pertaining to Admiralty Island as well as providing citizen-funded science to aid in the decision-making process. Friends supports the protection of the unique values for which the island was declared a National Monument. Members of Friends include sport and commercial fishers, hunters and guides, citizens of federally recognized Tribes, outdoor recreation enthusiasts and visitors to this national and global treasure.

Friends began a more concerted effort to monitor the Greens Creek Mine when it discovered the original 1981 pre-mining baseline had not been replicated and that oversight and monitoring by both the Forest Service and the Alaska Department of Environmental Conservation (ADEC) was close to non-existent. After unsuccessful requests to ADEC, the Forest Service, and the Alaska Department of Fish and Game to update baseline studies, Friends has worked to prepare its own studies of metal contamination in biota and sediments.

Friends has long advocated that cultural values, as stated in the original proclamation and subsequently in ANILCA, must be a key consideration in the management of the Monument. Angoon is the only village on Admiralty. It has 10,000 years of cultural identity to the Island, for which subsistence is critical. The Elders successfully campaigned for the Island to be declared a National Monument as a way to protect their culture.

Friends maintains that meaningful consultation by the Forest Service with Angoon—on any Admiralty project—is required. While Friends does not speak for Angoon and is not authorized to represent its interests in this objection, it observes that meaningful consultation is not reflected in the 2024 FSEIS or the Draft ROD. Nor has the Forest Service adequately considered the impact of the proposed expansion on tribal citizens' subsistence cultural practices as part of its

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[19] *See* Friends of Admiralty Island, Letter to M. Reese, U.S. Forest Service, Re: Comments on No. 20230041, Draft Supplement, Environmental Impact Study Greens Creek Mine North Extension Project (2023 sDEIS) (May 23, 2023) (2023 DSEIS Comments).
Additionally, all documents cited in this objection will be submitted to the Forest Service on March 15, 2024 (with the exception of statutes, regulations, Forest Service documents (forest plans, Forest Service Handbook, etc.), and documents cited in the planning documentation) with this objection. *See* 36 C.F.R. § 218.8(b). When citing to specific documents included in the 2024 FSEIS, Draft ROD or other Forest Service planning records, the objection refers to the individual document page number.

[20] *See* Earthjustice, Letter to F. Sherman, Forest Supervisor, Re: Greens Creek Mine North Extension Project (Dec. 18, 2023) (2023 Earthjustice Letter).

obligation to protect Monument values. Whether subsistence foods are safe or not is only part of the problem. When tribal citizens avoid Hawk Inlet as a source of subsistence foods because of a perception that those foods are unsafe, that is a profound loss to the community that the Forest Service must document and acknowledge as an impact of extending the life of the mine. The Forest Service has failed to acknowledge this loss of ability to continue cultural practices that undercuts foundational Monument values.[21] The Forest Service should delay its decision until the Angoon Community Association is satisfied that they have been meaningfully consulted.

Friends has also participated in past mine project expansion reviews and authorizations. Friends submitted comments on both the 2003 EIS and 2013 EIS. Friends has also provided extensive citizen science that helped inform the Clean Water Act 303(d) Total Maximum Daily Load analysis conducted by ADEC in 2016 but is entirely absent in the 2024 FSEIS. Friends also provided an analysis of lead level trends in clams shells documenting hundreds of years of conditions in Hawk Inlet and in Young Bay used as natural area for comparison. This data showed recent significant increases in lead levels of clam shells in Hawk Inlet as compared to the past and as compared to Young Bay.[22] The Forest Service dismissed this data in the 2024 FSEIS without comment.

For purposes of 36 C.F.R. § 218.8(d)(1), the objecting party may be contacted at the name, address and telephone number indicated in the signature block.

STATEMENT OF ISSUES, INCONSISTENCY, AND ILLEGALITY

As explained below, this objection addresses the Greens Creek Extension Project, as well as the supporting 2024 FSEIS and the Draft ROD. The objection addresses the specific issues of concern below.[23]

The objection identifies concerns over compliance with ANILCA and failure to comply with NEPA regarding impacts associated with fugitive dust.

In conformance with 36 C.F.R. § 218.8(c), each substantive section also demonstrates the connection between specific sections of the 2023 DSEIS Comments and/or explains that a specific issue arose after the opportunity for formal comment.

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[21] 2024 FSEIS, App. C at C-275 (responding to Comment 331-7).

[22] *See* Friends, *Evaluation of Stable Isotope Ratios and Lead Concentrations in Clam Shells Over Time in Hawk Inlet* (Dec. 12, 2022).

[23] *See generally* 36 C.F.R § 218.8(d)(5).

I. THE FOREST SERVICE FAILED TO ENSURE THAT ALL MEASURES HAVE BEEN TAKEN TO AVOID HARM TO THE MONUMENT AND ITS RESOURCES[24]

A. ANILCA and Forest Service regulations impose requirements on mining activities within the Monument.

Section 503(i)(1) of ANILCA provides that the Greens Creek Mine is entitled to a lease only if certain conditions are met.[25] Specifically, the Secretary of Agriculture must find that private lands are unavailable for the proposed mining activities, the proposed use will not irreparably harm Monument values, and the use of those public lands will cause less environmental harm than use of other reasonably available lands.[26] Further, Forest Service regulations promulgated pursuant to section 503(f)(2)(A) of ANILCA require mining operations to include all feasible measures to prevent or minimize potential adverse impacts on the Monument.[27] These regulations also require operators to take all practicable measures to maintain and protect fisheries and wildlife habitat.[28] The Forest Service must articulate a rational connection between the information before it and the conclusion that these requirements have been met but has failed to do so.

B. The Forest Service failed to follow its own past recommendations for future decisions to authorize expansion.[29]

In 2013, the Forest Supervisor recognized he was making an "unusually difficult decision" and that future decisions would need more information to "avoid [the] dilemma" regarding future expansion and compliance with ANILCA.[30] At that time, the Forest Supervisor identified that he was "adopting an alternative that provides only a relatively short-term solution to the issues related to tailings disposal and protection of [the Monument]."[31] The Forest Supervisor cautioned that two steps must be taken to ensure that "the Responsible Official for the next decision not be in the position I am today."[32] The Forest Service has failed to heed this caution.

The first measure identified in the 2013 ROD was for the Forest Service to develop Forest Service directives "to clarify how to apply the complex set of legal requirements that are specific to [the Monument]."[33] The Forest Service has not supplemented its directives as recommended to avoid the peril of making, yet again, another short-term decision that places the Monument further at risk of irreparable harm.

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[24] Friends raised these issues with the Forest Service in both its 2023 DSEIS Comments, *see id.* at 1-7, and in the 2023 Earthjustice Letter. .

[25] *See* Pub. L. 96-487, § 503(i)(1); *see also* Draft ROD at 13, 18-19 (same).

[26] *Id.*

[27] 36 C.F.R. § 228.80; *see also* ANILCA § 503(f)(2)(A); *see* Draft ROD at 19 (same).

[28] 36 C.F.R. § 228.8(e).

[29] Friends raised issues regarding the Forest Service's failure to follow its 2013 recommendations in its comment letter. 2023 DSEIS Comments at 13–14.

[30] *See* 2013 ROD at 14.

[31] *Id.*

[32] *Id.*

[33] *Id.*

The second step identified was for Hecla to provide feasibility analyses regarding the construction and use of alternative tailings disposal facilities.[34] In 2013, the Forest Supervisor was clear that future decisions regarding expansion would need to be supported by these analyses.[35] To the Friends' knowledge, Hecla never provided these analyses to the Forest Service, and no such analyses are referenced by the Forest Service in the 2023 DSEIS or 2024 FSEIS.

In stark contrast to the recommendations offered over 10 years ago, both the 2023 DSEIS and 2024 FSEIS summarily state that alternatives locating tailings disposal facilities outside the Monument are not feasible and that the proposed expansion alternative would not cause irreparable harm.[36] In Appendix A, referenced in both the DSEIS and FSEIS, the Forest Service asserts that the additional legal and factual information required by the Forest Supervisor in 2013 is only relevant to a southward extension of the tailings stack.[37] The Forest Service's assumptions regarding relevance are misplaced. Information regarding feasibility of siting tailings facilities is critical when considering any further expansion of the tailings stack within the Monument. Any such expansion requires the Forest Service to make findings about feasibility and irreparable harm and absent a record to support what is or is not feasible, conclusions based on Hecla statements are unfounded and arbitrary.

Rather than taking the requisite step of obtaining underlying additional feasibility information from Hecla, the Forest Service contradicts itself and its Forest Supervisor's 2013 finding that tailings alternatives outside the Monument may be feasible in both the 2023 DSEIS and the 2024 FSEIS. Instead, in both the draft and final version of the supplemental environmental impact statement, the Forest Service adopts Hecla's assertion regarding feasibility without providing any explanation for the revised conclusion.[38]

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[34] *Id*. at 15.

[35] *Id.*

[36] 2023 DSEIS at 2-9, 2-32; 2024 FSEIS at 2-9, 2-32 (same).

[37] Appendix A to both the 2023 DSEIS and 2024 FSEIS, Sec. 3.1.3, at 3-5. *Compare* with 2013 ROD at 12 (conflicting with the current Forest Service position where the Forest Service formerly stated that "[i]t also appears that many people have assumed that Section 503(i)(1) applies only to activities within the Monument. After studying the language carefully, I have reached a different conclusion: that the provisions apply on any National Forest System land, including land within the Monument *and land outside its boundary*.") (emphasis added).

[38] 2023 DSEIS at 2-32 ("These options . . . were not technically or economically feasible.") and 2024 FSEIS at 2-33 (same); *compare with F.C.C. v. Fox Television Stations, Inc.*, 556 U.S. 502, 515 (2009) (holding that an agency must provide a more detailed justification when a new policy "rests upon factual findings that contradict those which underlay its prior policy").

C. The Forest Service's approach to determining irreparable harm is inconsistent with ANILCA.[39]

Instead of clarifying how to apply ANILCA's requirements to the Monument, both the 2023 DSEIS and 2024 FSEIS fundamentally misconstrue the statute. In both documents, the Forest Service establishes a kind of geographic significance test, stating that the proposed expansion alternative would not cause irreparable harm "based on the expected 2.3 [additional] acres (0.0002 percent) of disturbance in the Monument."[40]

Both the 2023 DSEIS and 2024 FSEIS also discount any "measurable" effect on Monument resources because 1) new disturbance to the Monument surface would occur within the existing lease boundary; 2) there are no documented cultural sites in the area to be disturbed; 3) new surface disturbance would be next to existing disturbance; and 4) the design and use of the realigned road segment in the proposal would remain generally the same as under the no action alternative.[41] This approach is arbitrary for two reasons.

First, Congress did not set any geographic threshold for what constitutes irreparable harm, and to do so would be inconsistent with Congressional intent because it dilutes the standard to the point of meaninglessness.[42] All of Hecla's subsurface rights put together encompass just 7,300 acres—less than one percent of the total Monument area of 956,155 acres. Congress was aware of this when ANILCA was enacted, and nonetheless prohibited leasing of lands for mining and milling purposes in connection with those claims where it would cause irreparable harm. It is clear that Congress recognized damage to even a small portion of the total Monument area could be irreparable.

Second, the Forest Service's rationale relies on factors irrelevant to the statutory requirements, such as the amount of surface disturbance that would be confined to the existing lease boundary and its adjacency to existing disturbance, and fails to explain why the harm caused would not violate ANILCA.[43] The Forest Service must articulate a rationale that addresses the nature of the harm caused by the proposed additional surface disturbance and the many ways in which operating the mine for another 12 to 18 years could cause irreparable harm to the Monument. Moreover, the Forest Service must acknowledge and investigate the substantial risk that the mine is *already* causing irreparable damage to the Monument, such that the proposed expansion would

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[39] Friends raised issues regarding the Forest Service's failure to properly assess harm to the Monument in its 2023 DEIS Comments letter and in the 2023 Earthjustice Letter. 2023 DEIS Comments at 12-13; *see* 2023 Earthjustice Letter.

[40] 2023 DSEIS at 3-300; 2024 FSEIS at 3-305 (same).

[41] 2023 DSEIS at 3-299; 2024 FSEIS at 3-304.

[42] *See Ctr. for Biological Diversity v. Jewell,* 248 F. Supp. 3d 946, 958 (D. Ariz. 2017), *amended in part*, No. CV-14-02506-TUC-RM, 2017 WL 8788052 (D. Ariz. Oct. 25, 2017) (holding an agency may not interpret a statute so as to render a key statutory provision meaningless) (citing *Nat. Res. Def. Council v. Nat. Marine Fisheries Serv.*, 421 F.3d 872, 881 (9th Cir. 2005)).

[43] *See Motor Vehicle Mfrs. Ass'n of U.S., Inc. v. State Farm Mut. Auto. Ins. Co.*, 463 U.S. 29, 43 (1983) (agency action is arbitrary and capricious if the agency does not articulate a satisfactory explanation for its actions or has relied on factors which Congress has not intended it to consider).

only perpetuate that harm for decades absent more substantial mitigation and oversight. The Forest Service must implement ANILCA's requirements in a manner that is consistent with the statute's text and legislative history, and that acknowledges the Forest Service's prior findings. It has failed to do so.

D. The Forest Service failed to follow Friends' recommendations to ensure compliance with ANILCA.[44]

Friends identified several actions the Forest Service could take prior to approving any expansion to ensure it was complying with ANILCA.[45] Those measures included:

- Explain the agency's conclusions about the feasibility of tailings alternatives outside the Monument, and why those conclusions differ from the Forest Supervisor's findings in 2013.
- Reconsider whether the proposed expansion violates ANILCA's prohibition on irreparable harm to the Monument, taking into account the proposed expansion's effects on Monument values and on the life of the mine, *i.e.*, the cumulative impacts of extending operation and delaying reclamation for 12 to 18 years.
- Condition any new lease on more robust monitoring and reporting requirements that monitor for irreparable harm directly, including by monitoring for impacts on deer, eagles, bears, and humans, including sub-lethal impacts such as accumulation of heavy metals and changes to the overall species diversity and populations of species in the Monument including tidelands.
- Ensure that the Forest Service's leasing decision does not defer to State of Alaska monitoring and reporting requirements unless those requirements are also specific, enforceable conditions of the federal mineral lease.
- Condition any new lease on enforceable limits designed to prevent irreparable harm, including enforceable limits on fugitive dust.
- Repeat the pre-mining work that established baseline data for the mine, including by documenting the species diversity in the intertidal zone in Hawk Inlet. The goal of repeating this work should be to determine whether the mine has already caused irreparable harm, which would preclude further expansion until that harm is addressed.

The Forest Service has not followed or proposed any of these or similar measures that would avoid, mitigate and/or minimize harm to Monument resources. However, the Forest Service could resolve this objection by adopting these recommendations, or, potentially, by explaining why these measures cannot be incorporated into the Forest Service's authorization.

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[44] Friends identified possible mitigation measures in the 2023 Earthjustice Letter. 2023 Earthjustice Letter at 3-4.

[45] *See id*.

II. THE FSEIS FAILS TO ESTABLISH A PROPER ENVIRONMENTAL BASELINE

A. The 2024 FSEIS fails to establish a proper baseline for fish and wildlife.[46]

The 2024 FSEIS does not address concerns raised by Friends regarding the changing environment since mining operations began and establish a baseline that adequately reflects those changed conditions, as they relate to existing mine operations.[47] The establishment of a "baseline is not an independent legal requirement, but rather, a practical requirement in environmental analysis often employed to identify the environmental consequences of a proposed agency action."[48] An environmental impact statement must "succinctly describe the environment of the area(s) to be affected . . . by the alternatives under consideration."[49] Further, "[a]ccurate scientific analysis . . . [is] essential to implementing NEPA."[50]

In the 2024 FSEIS, the Forest Service response to comments regarding its baseline states that "[f]ollow-up studies to the 1981 Baseline include the Aquatic Biomonitoring Report (ADFG 2022), ADFG 19-01 Technical Report - Freshwater Resource Investigations Near Greens Creek Mine (ADFG 2020), Surface Water Hydrology Baseline Report (EDE 2021), Hawk Inlet Annual Monitoring Report (HGCMC 2022), and Environmental Risk Characterization Report (HGCMC 2021)."[51] While inclusion of monitoring reports may aid in establishing the baseline, the Forest Service has failed to identify how the environment has changed over time and what has led to those changes.

For example, Friends raised concerns that the baseline did not adequately address the growing decline of Pacific herring.[52] Friends noted that Pacific herring is a keystone species and that while it spawned in Hawk Inlet prior to commencement of mine operations, by 2013, it was only found spawning near the inlet.[53] Yet, the Forest Service provides no new information since 2013.[54] Instead, the 2024 FSEIS simply restates the baseline finding from 2013.[55]

Reliance on ten-year old data renders the FSEIS analysis arbitrary. In *Northern Plains Resources Council v. Surface Transportation Board*, the Ninth Circuit found that the Surface Transportation Board (Board) failed to take the requisite hard look under NEPA when it relied on similarly old data.[56] There, the Board elected to not conduct on the ground surveys for logistical reasons;

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[46] Friends raised issues regarding the Forest Service's failure to properly assess harm to the Monument in its comment letter. 2023 DSEIS Comments at 5–7.

[47] *See id.*

[48] *Am. Rivers v. FERC*, 201 F.3d 1186, 1195 n.15 (9th Cir. 1999).

[49] 40 C.F.R. § 1502.15.

[50] *Id.*

[51] 2024 FSEIS, App. C at 21-1 (responding to Comment 344-4, among others).

[52] *See* 2023 DSEIS Comments at 5.

[53] *Id.*

[54] *See* 2013 FEIS at 3-85.

[55] *See* 2024 FSEIS at 3-119 to 3-120. It is notable that the 2024 FSEIS only mentions Pacific herring twice throughout the entire EIS with no substantive analysis of how the project is impacting the species. *See id.* at 3-120.

[56] 68 F.3d 1067, 1086-87 (9th Cir. 2011).

instead relying on aerial surveys that were ten to twenty-two years old.[57] The Ninth Circuit found that reliance on stale aerial surveys did not meet the hard look standard.[58]

As a keystone species, with an identified change in occupation of habitat since mining commenced, the Forest Service must establish a baseline for 2023 that represents the current state for Pacific herring and how mining has or has not led to changes in the species' population and behavior. It failed to do so.

Friends also expressed concern over the 2024 FSEIS's failure to identify the potential decline of bald eagle nesting sites in Hawk Inlet, as part of the baseline.[59] In surveys relied on in the 1983 EIS, 23 eagles nest sites were identified in and around Hawk Inlet.[60] The 2024 FSEIS relies on a survey from 2019 that identified 16 sites in the project area, six of which were occupied and five of which were at Hawk Inlet.[61] The 2024 FSEIS does not specify if any of the Hawk Inlet nests were occupied. Nor does it acknowledge whether there is a downward trend in nest sites at Hawk Inlet. The baseline fails to capture the current state of bald eagles at Hawk Inlet, despite the fact that bald eagles are a management indicator species.[62] Without knowing whether bald eagles are avoiding Hawk Inlet, it is not possible to understand the full impacts of mining, as they exist today, let alone into the future with further expansion.

Friends also expressed concern over the failure to quantify, or even acknowledge, the decline in clams at the Greens Creek Delta.[63] In 1981, prior to commencement of mine operations, population estimates for Littleneck clams (*Protothaca staminea*) at the Greens Creek Delta were an average of 26 individuals per square meter (M^2) over five sites in the intertidal region and an average of 137 individuals per M^2 over five sites in the subtidal region.[64] In 1981, the intertidal region at the cannery had an estimated 157 individuals per M^2 Littleneck clams.[65] These locations match up with sites that are currently monitored for metals.[66] In 2007, the Hawk Inlet Monitoring Report found that populations present in Hawk Inlet were "relatively sparse."[67] By 2016, the Alaska Department of Fish and Game could not find a single Littleneck clam on the Greens Creek Delta.[68]

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[57] *Id*. at 1085-86.

[58] *Id*. at 1086 (citing *Lands Council v. Powell*, 395 F.3d 1019, 1031 (9th Cir.2005) (finding that six-year-old data, without updated habitat surveys, was too stale).

[59] *See* 2023 DSEIS Comments at 5-6.

[60] *Id*. citing 1983 EIS, Fig. 3-26 at 3-78.

[61] 2024 FSEIS at 3-209.

[62] *See id.* at 3-207.

[63] *See* 2023 DSEIS Comments at 6.

[64] *See* Martin Marietta Environmental Center, Final Field Results of the 1981 Field Program for the Greens Creek Project, Part 1 -- Hawk Inlet and Young Bay at B-4 (Oct. 1981).

[65] *Id*. at B-8.

[66] *See* 2023 DSEIS Comments at 6.

[67] *See* Kennecott Greens Creek Mining Co., Hawk Inlet Monitoring Program, 2007 Annual Report at Sec. 4.1 (Jan. 2008).

[68] *See* K. Herbert, Alaska Department of Fish and Game, Memorandum to file: Hawk Inlet Intertidal Clam Investigation (Dec 15, 2016).

In contrast to data found in the monitoring reports by the State, the 2024 FSEIS again relies on the 2013 baseline.[69] And at odds with those monitoring reports, the 2024 FSEIS puts forth the 2013 conclusion that "[e]xtensive beds of littleneck clam (*Protothaca staminea*) . . . are also present."[70] This is the single reference to Littleneck clams in the entire 2024 FSEIS. The Forest Service again relies on stale data, failing to undertake the requisite hard look at impacts to wildlife.

The 2024 FSEIS also ignores pre-mining measurements of natural conditions, including data pertaining to heavy metals in deer, eagles and bear, as well as species diversity and population studies in the intertidal zone of Hawk Inlet on specious grounds.[71] The Forest Service dismisses consideration of past data, in part, on the grounds that detection limits are more sensitive than they once were, precluding comparisons.[72] This reasoning fails to recognize that past data informs current decision making and that comparisons, based on improved technology, only further inform the Forest Service about how conditions have changed for the better or worse. The Forest Service also ignores past species diversity and population data, recorded prior to commencement of mining; instead relying on ADEC monitoring reports.[73] While ADEC monitoring reports identify increases in contaminants, the 2024 FSEIS fails to recognize the change in heavy metal concentrations over time and defers to ADEC's unsupported conclusions about increases occurring due to natural processes without evaluating how fugitive dust could be contributing to these increases.

The Forest Service has failed to provide an adequate baseline of wildlife in the project area. It has also failed to establish whether there are population changes in the diversity of species present or behavioral trends that may indicate adverse impacts from mine operations. This is critical information to understand the current conditions and how future expansion could further drive those trends. By failing to obtain current data, the Forest Service rendered its review arbitrary.

B. Mitigation and monitoring are not proxies for an adequate baseline.[74]

In addition to justifying its inadequate baseline based on past studies and monitoring reports, the 2024 FSEIS also states that there are a number of additional mitigation and monitoring measures included to address potential effects.[75] It is unclear to Friends whether the Forest Service is asserting that any of these additional measures would alleviate issues with the baseline. To the extent the Forest Service relies on mitigation to justify its inadequate baseline, that reliance is misplaced.

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[69] *See* 2024 FSEIS at 3-119.

[70] *Id.* at 3-120.

[71] *See* 2023 DSEIS Comments at 11–13.

[72] *See* 2024 FSEIS, App. C at 21-1.

[73] *See* 2023 DSEIS Comments at 20-23; *see* 2024 FSEIS, App. C at C-312, C-19 to C-20, C-21, C-244 to C-245, C-247 to C-249.

[74] This objection is based on new information that arose in the FSEIS Response to Comments. *See* FSEIS, App. C at C-19 to C-20 (responding to Comment 344-4, among others).

[75] *See id.*

As the Ninth Circuit has noted, mitigation measures are not sufficient to meet NEPA's obligations to determine the projected extent of the environmental harm to enumerated resources before a project is approved.[76] The court went on to note that:

> [m]itigation measures may help alleviate impact *after* construction, but do not help to evaluate and understand the impact before construction. In a way, reliance on mitigation measures presupposes approval. It assumes that—regardless of what effects construction may have on resources—there are mitigation measures that might counteract the effect without first understanding the extent of the problem.[77]

The court highlighted that NEPA not only ensures that agencies consider information pertaining to environmental impacts but also "guarantee[s that] relevant information is available to the public."[78] Mitigation measures cannot serve as a proxy for baseline data.[79] Without a proper baseline, the agency "cannot carefully consider information about significant environment impacts."[80] And regardless of the degree to which those measures guarantee data will be collected, "the data is not available during the EIS process and is not available to the public for comment."[81] Without this critical information, the "EIS cannot serve its larger informational role, and the public is deprived of their opportunity to play a role in the decision-making process."[82]

The 2024 FSEIS fails for this exact reason. The baseline fails to provide requisite information to inform both the public and the decision-maker prior to making its decision. By failing to collect the requisite data and provide it in the environmental impact statement, the Forest Service failed to take a sufficient hard look when it deferred gathering these baseline elements.[83]

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[76] *See N. Plains Res. Council, Inc. v. Surface Transp. Bd.,* 668 F.3d 1067, 1084 (9th Cir. 2011).
[77] *Id.* at 1084-85.
[78] *Id*. at 1085 (internal citations omitted).
[79] *Id.*
[80] *Id.*
[81] *Id.*
[82] *Id.* (internal citation omitted).
[83] *See id.* (finding agency violated NEPA by not collecting requisite baseline information); *see also Cent. Or. Landwatch v. Connaughton*, 905 F.Supp.2d 1192, 1197 (D. Or. 2012) (finding that an agency may violate NEPA where it ignores existing data).

III. THE FEIS FAILS TO TAKE THE REQUISITE HARD LOOK AT DIRECT, INDIRECT AND CUMULATIVE IMPACTS.[84]

A. The 2024 FSEIS's assessment of mitigation measures is insufficient.[85]

The 2024 FSEIS fails to adequately assess mitigation measures to address fugitive dust. In the 2013 EIS, the Forest Service identified that it needed to "further assess[] fugitive dust including mitigation and monitoring."[86] While the 2024 FSEIS acknowledges this need, it fails to conduct the requisite assessment. This failure is problematic given the 2024 FSEIS's recognition that "the results of the fugitive dust deposition modeling performed for the Project suggest that elevated levels of dust deposition, including metals, may be found for several thousand feet downwind of the [tailings disposal facility]"[87] The 2024 FSEIS further acknowledges that there would be increasing fugitive dust cumulative deposition over the extended life of the mine.[88] The 2024 FSEIS identifies that there would be deposition across watersheds and Hawk Inlet and that "[t]he high dust deposition areas are areas where mitigation and monitoring measures could be implemented."[89]

Despite recognizing that the project is likely to lead to increased deposition, the 2024 FSEIS fails to assess how mitigation measures may counteract that effect. This is problematic because the 2024 FSEIS recognizes that "[e]xisting mitigation measures to minimize the mobilization of fugitive dust from wind erosion of tailings at the [tailings disposal facility] are insufficient . . . ."[90] Rather than addressing how mitigation has been insufficient, the 2024 FSEIS simply states that phase 2 of the Project will not commence unless monitoring shows that mitigation measures are leading to a "long-term downward trend of environmental effects."[91] The 2024 FSEIS concludes that mobilization of fugitive dust will be minimized by "[k]ey features of the Fugitive Dust Mitigation and Monitoring Plan," which include a list of activities like reduction of open active tailings placement and use of adaptive management practices like watering or wind breaks.[92] There is no discussion in Section 3.2.2.7 regarding how these additional measures will minimize and reduce fugitive dust or how the measures will be monitored and evaluated for effectiveness.

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[84] Friends raised these issues with the Forest Service in its 2023 DSEIS Comments; *see also* 2024 FSEIS, App. C at C-314 to C-315, C-317, C-321, C-322.

[85] Friends raised issues regarding mitigation and monitoring pertaining to fugitive dust in its comment letter. 2023 DSEIS Comments at 15–18.

[86] 2024 FSEIS at 3-16.

[87] *Id.* at 3-39; *see also id.* at 3-36 (recognizing that "[a]mounts of deposition are of concern for potential impacts on water resources, aquatic life, and other biological and human resources.").

[88] *Id.* at 3-16; *see also id.* at 3-36.

[89] *Id.* at 3-16 to 3-17.

[90] *Id.* at 3-39.

[91] *Id.*

[92] *Id.* at 3-40.

Mere listing of potential mitigation activities is insufficient. A hard look analysis under NEPA requires the Forest Service to look at how these measures would reduce harms.[93] As the Ninth Circuit noted in *Neighbors of Cuddy Mountain v. U.S. Forest Service*, "[t]he Forest Service's perfunctory description of mitigating measures is inconsistent with the 'hard look' it is required to render under NEPA. Mitigation must be discussed in sufficient detail to ensure that environmental consequences have been fairly evaluated."[94] Here, the 2024 FSEIS inappropriately limits its discussion to listing activities without discussing how such measures will actually reduce fugitive dust and limit impacts to the environment. This lacking assessment fails to meet the hard look requirement.

B. The 2024 FSEIS fails to take the requisite hard look at fugitive dust impacts on Hawk Inlet and Tributary Creek.[95]

The Forest Service errs in its review of fugitive dust impacts on Hawk Inlet and other water bodies, including Tributary Creek. Hawk Inlet carries both ecological and cultural importance.

While the 2024 FSEIS recognizes that fugitive dust will potentially be deposited in Hawk Inlet and Tributary Creek, that metals will leach from dust into nearby creeks through precipitation events, and that water quality could be affected, it fails to adequately support the conclusion that there are not likely to be water quality standard exceedances due to dust.[96] As discussed above, monitoring has shown a downward trend for organisms in Hawk Inlet. In Hecla's 2022 Hawk Inlet monitoring report, findings indicated that lead concentrations in biota tissue samples have increased at all sample sites, as compared to pre-mining data.[97] Biota tissue samples for *Nephtys* also showed increases in lead concentrations, as compared to pre-mining data.[98] Yet, the 2024 FSEIS fails to set out how increased contamination for species in Hawk Inlet or other waterbodies may impact these species and the ecosystem over time. Given that the 2024 FSEIS recognizes there will be an increase in fugitive dust deposition in these waterbodies and that there has been documented increase in lead contamination since mine operations began, the 2024 FSEIS has failed to take the requisite hard look at ongoing and future impacts from dust contamination.

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[93] *See S. Fork Band Council of W. Shoshone Of Nevada v. U.S. Dep't of Interior*, 588 F.3d 718, 727 (9th Cir. 2009) (finding the Bureau of Land Management's assessment of mitigation inadequate and rejecting the agency's argument that an effectiveness discussion was not required because it is impossible to predict the precise location and extent of groundwater reduction, and that problems should instead be identified and addressed as they arise); *Nw. Indian Cemetery Protective Ass'n. v. Peterson,* 795 F.2d 688, 697 (9th Cir.1986), *rev'd on other grounds,* 485 U.S. 439 (1988) ("A mere listing of mitigation measures is insufficient to qualify as the reasoned discussion required by NEPA.").

[94] 137 F.3d 1372, 1380 (9th Cir. 1998) (internal quotations and citations omitted).

[95] Friends raised issues regarding fugitive dust impacts to Hawk Inlet and Tributary Creek in its comment letter. 2023 DSEIS Comments at 3–13, 17, 25, 27.

[96] 2024 FSEIS at 3-77 to 3-78.

[97] *See* Hecla, Hawk Inlet Monitoring Program, 2022 Annual Report at 14, Tbl. 4-2 (Feb. 27, 2023).

[98] *Id*. at 15, Tbl. 4-3.

CONCLUSION

The Forest Service continues to authorize expansions of the Greens Creek Mine tailings facility without considering the full scale of impacts associated with expansion. Further, the Forest Service fails to meet the requirements of ANILCA through these piece-meal authorizations of expansion and their associated impacts on Monument resources. While the Forest Service recognized the need for detailed information in 2013, through its current analysis and the Draft ROD, it has abandoned its previous cautions to the detriment of the Monument, its resources and the Admiralty Island ecosystem. Rather than providing Hecla with yet another authorization to expand its tailings facility, the Forest Service should reassess all alternatives, gather the requisite information it identified in 2013, review and respond to all proposed mitigation measures provided by Friends, and proceed with a more informed review that will ensure the Monument is not irreparably harmed and that mining associated impacts are minimized and mitigated to the full extent possible.

Erin Colón
EARTHJUSTICE
441 W 5th Avenue Suite 301
Anchorage, AK 99501
T: 907.277.2500
E: ecolon@earthjustice.org

KJ Metcalf
FRIENDS OF ADMIRALTY ISLAND
P.O. Box 20791
Juneau, AK 99802
T: 907.500.2894

DOCUMENTS IN SUPPORT OF FRIENDS OF ADMIRALTY ISLAND'S OBJECTION TO THE GREENS CREEK MINE NORTH EXTENSION PROJECT

Friends of Admiralty, *Evaluation of Stable Isotope Ratios and Lead Concentrations in Clam Shells Over Time in Hawk Inlet* (Dec. 12, 2022)

Hecla Greens Creek Mining Co., Hawk Inlet Monitoring Program, 2022 Annual Report (Feb. 27, 2023)

K. Herbert, Alaska Department of Fish and Game, Memorandum to file: Hawk Inlet Intertidal Clam Investigation (Dec 15, 2016)

Kennecott Greens Creek Mining Co., Hawk Inlet Monitoring Program, 2007 Annual Report Jan. 2008)

Martin Marietta Environmental Center, Final Field Results of the 1981 Field Program for the Greens Creek Project, Part 1 -- Hawk Inlet and Young Bay (Oct. 1981)

A.W. West, *The History of Greens Creek Exploration* (2010)

Title: Evaluation of Stable Isotope Ratios and Lead Concentrations in Clam Shells Over Time in Hawk Inlet.

Friends of Admiralty
PO Box 20791, Juneau AK 99802
(907) 586-6738

Author: Guy Archibald
Date: December 12, 2022

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Abstract

Admiralty Island was designated as a National Monument in 1978 for its outstanding unspoiled ecosystem and its value for scientific studies. At the time of the designation, existing mining claims were grandfathered into the Monument. In 1980 Congress passed the Alaska National Interest Lands Conservation Act (ANICLA) that among other things, authorized mining activities on valid existing claims within the Monument under a higher standard than required under 1872 General Mining law "to provide environmental safeguards under which development of the claims can continue. . ." as long as mining will not cause irreparable harm to the Monument.

In 1989 these claims became the Greens Creek Mine producing silver, lead and zinc. The Greens Creek mine is the only mine in the United States allowed to operate within a National Monument.

Prior to mine development, extensive data were collected on the population and diversity of various macroinvertebrate species along the littoral zone in nearby Hawk Inlet. Blood samples were also collected from terrestrial consumers and predators on the surrounding uplands and analyzed for heavy metals. These data were to form the basis of a long-term program to monitor the effects of mining on the Monument.

For the most part, these studies have not been carried over and in their place, a program of measuring water, sediment and tissue chemistry was adopted. This monitoring, along with other studies, indicate lead levels have increased since mine operations began. These reports conclude that the increase of lead levels on the uplands is due to mine activities but that the increase of lead in the adjacent marine environment (Hawk Inlet) is due to natural erosion of the mineralized rocks in the area.

The goal of this study is to determine if the increase of lead in the marine environment is due to natural causes or the mine's activities. The study utilizes clam shells as an indicator of lead concentrations in the sediment and water at the time the clams were alive. Due to the natural uplift of the land, raised beach deposits supplied shells that could be used to create a timeline of conditions that existed hundreds of years prior to operations at the mine. The lead concentrations and the isotopic signatures in these pre-production era shells were then compared to living specimens representing conditions during the production era of the mine. The study also includes a nearby bay not subject to mining activities that serves as a natural conditions control area. In this report, we also seek to identify any other possible sources of Pb in Hawk Inlet.

This study concludes that the increase of lead in the marine environment is man-made and most likely due to fugitive dust emissions from the tailings pile entering the marine environment of Hawk Inlet at the Greens Creek delta. This is consistent with the reasons given for the observed increase of lead in the uplands.

1. *Introduction:*

The goal of this project was to identify the source of the of lead (Pb) in the marine environment at Hawk Inlet, Alaska and to distinguish between possible naturogenic (natural) and anthropogenic (human-caused) sources.

Hawk Inlet is located on northwest Admiralty Island in Southeast Alaska within the Tongass National Forest. On the east side of Hawk Inlet, Hecla Mining Company (Hecla) operates a concentrate loading facility and a dry stack tailings disposal facility (TDF) along with related infrastructure to support the operations of the Greens Creek Mine. The southeast side of the TDF is bordered by the Admiralty Island National Monument designated by Presidential proclamation in 1978. Greens Creek is a silver (Ag), lead (Pb), and zinc (Zn) mine that has been in operation since 1989 with a 2-year period of temporary closure.

Data collected during routine monitoring shows Pb levels in surrounding upland and marine environments have increased since mine operations began. Monitoring reports required by the State of Alaska assume the increase in Pb in the marine environment is within the range of natural conditions [1] and most likely is due to erosion of the mineralized geology in the area [2]. An increasing trend of Pb concentrations over time is not consistent with a natural source. Natural erosion occurs at basically the same rate over time and produces a monotonic trend unless some other factor (i.e., erosion) is also increasing. Neither Hecla nor the State of Alaska offer any evidence of an increase in the rate of erosion that would account for this trend.

In contrast, the increase of Pb observed in the uplands as measured by surface and ground water monitoring stations is assumed to be due to mining activities (surface disturbance or fugitive dust) and the presence of a boggy reducing environment contributing to the dissolution and mobility of Pb. No justification is offered by either Hecla or the State to account for using two separate mechanisms to explain the same observed phenomena. The marine environment is nearer mine operations than some of the terrestrial stations where Pb is observed to be increasing. All of the factors cited for the increase of Pb concentrations on land should also apply to the adjacent marine environment.

Lead contamination in the environment poses a risk to the health of natural ecosystems and resident organisms and can have devastating implications for human health. Environmental monitoring and assessment techniques, which evaluate the source, transport and fate of metals in the environment, are instrumental in assessing the impact of metal emissions and applying efficient remediation strategies. Some trace metals, e.g., Zn, are essential micronutrients (biologically necessary), whereas others such as Pb are non-essential and may be toxic even at low concentrations. According to the Alaska Department of Environmental Conservation (ADEC) there are no recommended safe value for human exposure to Pb because any level can have detrimental effects.

Pb occurs naturally and is often combined with two or more other elements to form Pb compounds. Mining and industrial activity have also introduced various forms of Pb into the environment through the intensive use of fossil fuels, particularly leaded gasoline [3].

In the marine food chain, Pb is bio-concentrated and not biomagnified due to its involvement in calcium turn-over systems in organisms, resulting in deposition in bones and shells rather than in soft tissues [4].

Bivalve (clam/mussel) shells have been used as effective indicators of ambient water and sediment quality at the point in time they are alive [5][6]. Each year the organism produces an incremental layer of shell composed primarily of calcium carbonate along with a small fraction of organic substances and various elements from the environment in which they live. These elements are simultaneously deposited in annual layers and are assumed to be essentially immobile [5]. Available Pb in the environment accumulates in shell material at higher rate than in tissue and therefore serves as a better indicator of environmental levels than tissue analysis.

Shell Pb concentrations have also been shown to be useful for predicting environmental exposures from single point sources when combined with stable isotope analysis [7]. In the recent years, a growing number of environmental science studies on Pb contamination were conducted using Pb stable isotopes to determine the source and origin of Pb observed in the environment. Pb has four stable isotopes (^{204}Pb, ^{206}Pb, ^{207}Pb and ^{208}Pb). Radioactive decay of ^{238}U, ^{235}U and ^{232}Th produces radiogenic lead isotopes (206, 207 and 208). ^{204}Pb is the only non-radiogenic lead isotope, therefore is not one of the daughter isotopes [8].

Research has used lead isotope ratios ($^{207/206}$Pb, $^{208/206}$Pb) as a signature, able to trace emission sources and to assess spatial and temporal changes of Pb pollution. [9] Various sources of Pb have specific isotopic signatures and can be used generally to distinguish between Pb originating from natural or anthropogenic sources. Pb isotope analysis has proved to be an effective technique for identifying the origin of Pb in terrestrial, marine and aquatic ecosystems [10]. The isotopic composition of Pb is not affected to any measurable extent by physical or chemical processes such as weathering [10].

Samples of clam shells from living organisms representing conditions during the current era of mine production and shells from raised marine deposits dated prior to mine activities (pre-production) were collected in Hawk Inlet and Young Bay. Young Bay serves as the control site free of most anthropogenic sources found in Hawk Inlet. The shells were analyzed for total Pb and the stable isotopes of Pb. A composite sample of tailings was obtained from Hecla Greens Creek Mining Company for comparison. Other possible anthropogenic sources of Pb in Hawk Inlet are also examined based on available data.

Land masses in the region, including Admiralty Island, are rising as compared to mean sea level due to a combination of isostatic rebound occurring since the last period of glaciation and tectonic forces. The rate of uplift in the region of Hawk Inlet has been accurately measured. Raised marine shell deposits were identified, sampled and dated based on their current elevation above mean low tide (MLT). MLT was used as representative of the level where bivalves occur when alive. The elevation of these deposits was compared to the known rate of uplift in the region in order to derive the time they were alive. Select samples were also dated by radiocarbon techniques to help verify the dates derived by elevation.

Study Location

Hawk Inlet is known by the Tlingit name of *Weinedel* meaning “Eelgrass Where Herring Spawn”. It is an approximately 7-mile-long marine estuary classified as fjord, extending north from Chatham Strait, located on the northern end of Admiralty Island in southeast Alaska. Admiralty Island is sacred to the people of Angoon, the only community on the island, who know it as *Xootsnoowú*, which is Tlingit for "Fortress of the Bear(s)". Hawk Inlet is used by the residents of Angoon as a source of subsistence foods and for cultural practices. It is also used for sport and commercial fishing by residents of Juneau, Hoonah and Tenakee Springs.

Hawk Inlet contains a 1.12-acre area of impaired marine sediments (Clean Water Act section 303(d)) near the Greens Creek Mine's concentrate loading facility. The area was contaminated in 1989 by a spill of ore concentrate into the marine and intertidal environment during loading operations. The concentrate was partially cleaned up by suction dredge a few years later. The extent of the contaminated area has never been fully delineated.

The major drainages into Hawk Inlet include Tributary Creek, which originates in the wetland now partially occupied by the mine's Tailings Disposal Facility (TDF). Greens Creek and Zinc Creek drain from nearby the mine's underground workings and converge on the Greens Creek Delta near the mouth of Hawk Inlet. Cannery Creek drains a small area north of the TDF entering Hawk Inlet near the concentrate loading station.

There are two permitted point-source discharges into Hawk Inlet for industrial wastewater disposal. Outfall 002 discharges treated water from a variety of mine activities including contact water from the TDF. Outfall 002 enters Hawk Inlet off the Greens Creek delta through an underwater diffuser into a 13,200 ft^2 chronic mixing zone, an area of Hawk Inlet regulatorily exempt from meeting Alaska's chronic water quality criteria for the protection of aquatic life. Within the chronic mixing zone is a smaller mixing zone of 10,176 ft^2 where the acute water quality criteria may also be exceeded. Alaska water quality criteria must be met outside the regulatory mixing zones [11].

Near the concentrate loading facility is a storm water discharge designated as Outfall 003. This discharge is monitored but not subject to effluent limitations. Additionally, there are numerous non-point source discharges either entering directly into Hawk Inlet or into the fresh water tributaries of Hawk Inlet. Some of these non-point source discharges are monitored by the mining company.

Hawk Inlet has a history of modern human influences including a small gold mine located at about 1000 feet of elevation 1.2 miles north of the Greens Creek delta in the uplands above the west side of Hawk Inlet. The Alaska Empire Mine operated intermittently from 1919 until 1946. The U.S. Forest Service and Alaska Department of Fish and Game have sampled water, sediment and tissues at locations thought to be influenced by the Empire Mine. In addition, a fish cannery operated at the site of the current concentrate loading facility from 1910 until it burned in 1976 leaving a debris field on the bottom of Hawk Inlet. This debris field is generally within the 303(d) impaired area.

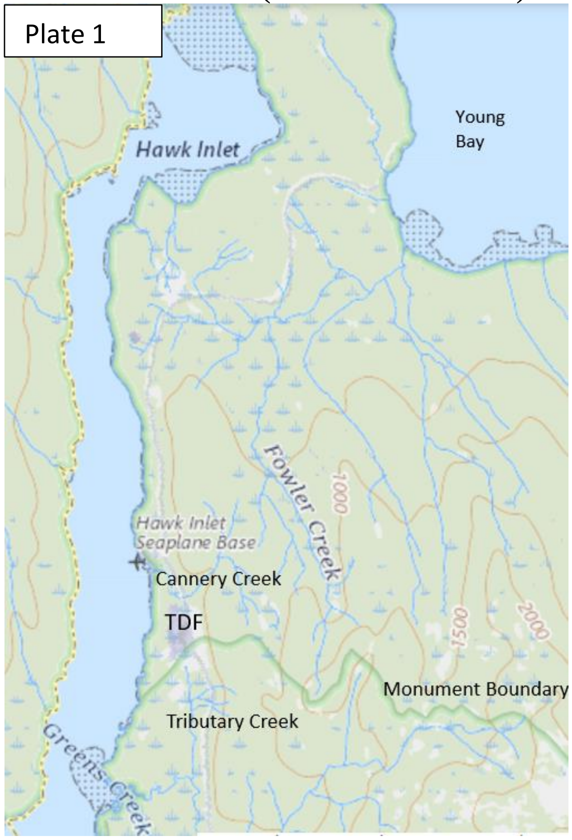
Young Bay is located on the east (opposite) side of Admiralty Island and separated from Hawk Inlet by a narrow, approximately half mile wide lowland. Young Bay contains the access dock for a crew boat arriving daily from Juneau transporting workers to the mine. Drainages into Young Bay include Fowler Creek and several unnamed tributaries. The Fowler Creek drainage basin is approximately 5,090 acres located on flat to moderately steep terrain and primarily covered by timber and forested wetlands. This watershed also drains a mineralized upland similar to the Hawk Inlet side as evident in the extensive amount of drilling conducted by Hecla Mining and as a designated Area of Interest for mineral exploration by the mining company [12].

2. Previous Investigations

3.1 Pre-Production Investigations.

At least three studies were conducted from 1978-1981 prior to mine activities in order to document baseline heavy metal concentrations in Hawk Inlet marine sediment and tissues from benthic organisms to higher trophic level organisms such as eagles, bear and deer in anticipation of the 1983 Environmental Impact Statement (EIS) for the proposed (then) Noranda Mining Project (VTN 1978, IEC 1980, Martin Marietta 1981). Fish tissue data was collected prior to production at Greens Creek and Zinc Creek (Richkus and Johnson 1981) and from a tributary to Zinc Creek in 1981 (Holland et al. 1981).

Plate 1



The 1983 EIS cited the protection of aquatic life in Hawk Inlet as the major threat. As such, a baseline aquatic life study was conducted in 1978 and 1979. The study documented species diversity and populations of macroinvertebrates in the intertidal zones of Hawk Inlet including along the Greens Creek delta. The study found healthy populations of numerous species of clams on the delta typical of other rocky beaches in southeast Alaska (Martin Marietta Environmental, 1981).

The blood of local Brown Bear (*Ursus arctos*) and eleven bald eagles (*Haliaeetus leucocephalus*) was collected and tested for metal levels in 1987 prior to the opening of the mine. Ten years later in 1997, blood from eight bald eagles was collected for comparison to the 1987 results. A comparison of Pb levels could not be made because the 1987 Pb detection limits were much higher and many of the concentrations measured in 1997 were not detectable in 1987. No other data from higher trophic levels has been collected since 1997.

Researchers characterized the findings as follows: "The concentrations observed were comparable to levels reported for "pristine" and "unpolluted" marine areas of the northeast Pacific coast and were orders of magnitude lower than levels reported for "polluted" or "semi-polluted" environments …. [13]. These data were quantitatively similar to data previously collected from Hawk Inlet by VTN, indicating that year to year variability in sediment metals is small" [14].

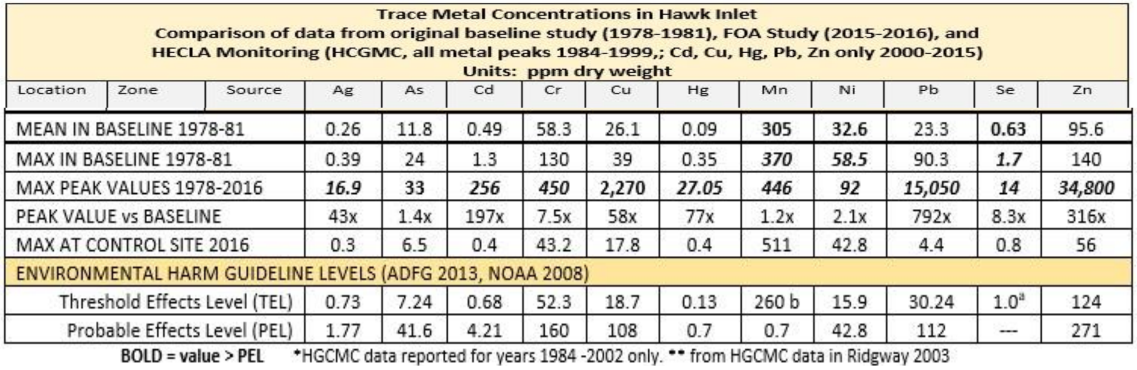
Since production began, tissue metal loading data in Hawk Inlet has been collected only on first order benthic organisms. No long-term data has been collected from upper trophic level consumers, fish, raptors or marine mammals that would give information on the rates or trends of Pb loading in the food chain and in upper trophic level animals. The species diversity and population study has not been repeated since the mine went into production.

3.2 Production-era Investigations

In 1997, after approximately 6 years of production and in preparation to expand the TDF, the USDA Forest Service conducted a lichen study to evaluate possible fugitive dust emissions from the TDF and the mine's road system. Lichens are well-known bioindicators of air quality. Lichens were collected along transects radiating outward from the TDF and along the roads. Contaminant concentrations were found to be above Tongass National Forest thresholds in all locations measured due to fugitive dust from mining activities. Many of the contaminants including Pb, cadmium (Cd), and sulfur (S) were the highest found in lichens anywhere on the Tongass National Forest [15].

A study facilitated by Friends of Admiralty (FOA) in 2015 compared 19 sediment samples collected from 13 sites in Hawk Inlet from the head of the inlet in the north to Pile Driver Cove in the south with pre-mining baseline levels [16].

Table 1: Summary of Metals in Sediment as Compared with Baseline at All Locations



Trace Metal Concentrations in Hawk Inlet
Comparison of data from original baseline study (1978-1981), FOA Study (2015-2016), and
HECLA Monitoring (HCGMC, all metal peaks 1984-1999,; Cd, Cu, Hg, Pb, Zn only 2000-2015)
Units: ppm dry weight

Location	Zone	Source	Ag	As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Se	Zn
MEAN IN BASELINE 1978-81			0.26	11.8	0.49	58.3	26.1	0.09	**305**	**32.6**	23.3	**0.63**	95.6
MAX IN BASELINE 1978-81			0.39	24	1.3	130	39	0.35	***370***	***58.5***	90.3	***1.7***	140
MAX PEAK VALUES 1978-2016			***16.9***	**33**	***256***	***450***	**2,270**	***27.05***	***446***	***92***	***15,050***	***14***	***34,800***
PEAK VALUE vs BASELINE			43x	1.4x	197x	7.5x	58x	77x	1.2x	2.1x	792x	8.3x	316x
MAX AT CONTROL SITE 2016			0.3	6.5	0.4	43.2	17.8	0.4	511	42.8	4.4	0.8	56
ENVIRONMENTAL HARM GUIDELINE LEVELS (ADFG 2013, NOAA 2008)													
Threshold Effects Level (TEL)			0.73	7.24	0.68	52.3	18.7	0.13	260 b	15.9	30.24	1.0[a]	124
Probable Effects Level (PEL)			1.77	41.6	4.21	160	108	0.7	0.7	42.8	112	---	271

BOLD = value > PEL *HGCMC data reported for years 1984 -2002 only. ** from HGCMC data in Ridgway 2003

Note: TEL represents the concentration below which adverse biological effects are expected to occur rarely. PEL defines the level above which adverse effects are expected to occur frequently.

FOA found the concentrations of all measured metals had increased substantially since mining began. The average increase for eleven metals was 73 times original baseline maximum levels, and 183 times the inlet-wide mean original baseline levels. FOA also compared Hawk Inlet with a control site in Young Bay. Young Bay showed relatively little to no change in most of the eleven trace metals analyzed in 1981 [16].

Another study facilitated by FOA in 2015 focused on benthic organisms commonly used for human consumption in Hawk Inlet. This study concluded "As, Cr, Cu, Pb, Ni and Se levels in Hawk Inlet blue mussels are two to five times higher in concentration in 2015 than levels reported in 1978, 1981 and 1984-1989 baseline levels measured prior to full operation of the industrial mine in the Hawk Inlet watershed" [17].

In 2016, the Alaska Department of Fish and Game conducted a survey to qualitatively characterize the intertidal clam community in Piledriver Cove and at the Greens Creek delta. Although the survey was not designed to produce rigorous statistical analysis, ADF&G reported that no living clams were observed on the Greens Creek Delta [18]. This is in stark contrast to the 1981 Martin Marietta Environmental report that found hundreds of individual clams living at the same location 35 years prior [18].

4. *Ongoing Monitoring by Hecla*

Hecla Greens Creek Mining conducts ADEC and EPA approved monitoring of water quality, sediment, and invertebrate tissue chemistry at several locations in Hawk Inlet. Seawater is sampled quarterly at three locations; 106, 107 and 108. Sediment and invertebrate samples are collected annually at three and seven spots respectively. See Plate 2. Additional sediment samples are collected at two other locations every five years.

4.1 Water Column Monitoring.

Water column chemistry is designed to monitor the mixing zone related to Outfall 002. Outfall 002 discharges through a submerged diffuser just off the end of the Greens Creek delta. The diffuser is 160 feet long with 15 discharge ports arraigned along it length. The diffuser is anchored to the bottom at a depth of 45 ft. near the shore of the delta and 69 ft. at the far end. Monitoring samples are collected quarterly at Station 108 located north of the mixing zone, station 107 north of the concentrate loading facility and station106 in Chatham Strait. All sites are sampled on an outgoing tide from a depth of five feet [19]. Quarterly data is compared to a five-year average. The most recent results (water year 2021) show Pb levels at or below detection limits at all sites [20].


Plate 2

4.2 Sediment Monitoring

The objective of sediment monitoring is to evaluate potential changes in the Hawk Inlet marine environment over time.

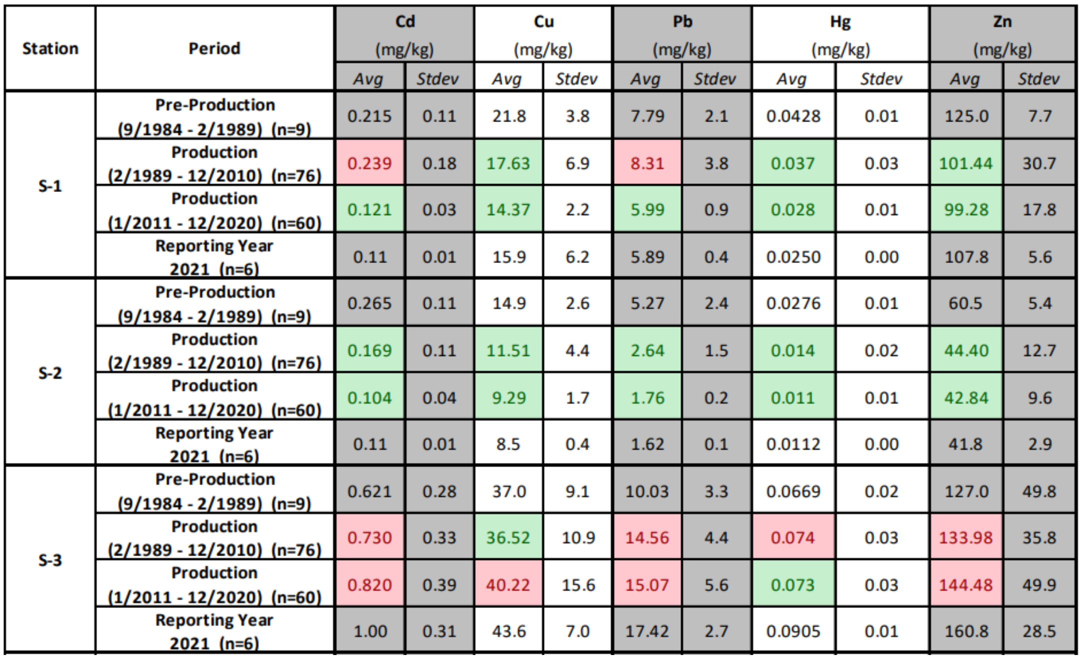
Sediment sites are sampled annually by Hecla. Site S-1 is located at the Greens Creek delta near the vicinity of Outfall 002. Site S-2 is a background site located over 1.5 miles to the south in Pile Driver Cove, and S-3 is located approximately 6 miles to the north of the delta at the head of Hawk Inlet. See Plate 2. Sediments at S-3 are listed as an area of concern under a State of Alaska Total Maximum Daily Load (TMDL) finding in 2017. The source of contamination at S-3 is unknown but the TMDL lists fugitive dust as a possible source [21].

Recently, (monitoring year 2021) Hecla began breaking down the production era results into two data sets, one comprised of 21 years of production (1989-2010) and the second comprised of the last 9 years of production (2011-2020) for the purposes of comparison with pre-production levels [20].

Average sediment Pb concentrations at S-1 have increased 6.5% during the 21-year production era (1989-2010) and decreased 26% in the last 9 years (2011-2020). At S-2, average Pb concentrations decreased 66% and 100% respectively for the two production periods as compared to the pre-production baseline. Average Pb levels at site S-3 have increased 37% during the first 21-year production era and 40% in the latest 9 years of production as compared to pre-production baseline.

Despite S-3's contamination and differences in sediment morphology (size and organic content) between sample sites, Hecla's monitoring data at S-3 and S-2 are used to evaluate results from the monitoring station at S-1 and conclude that the increase in Pb concentrations at S-1 is natural "given that S-1 is geographically located between the two sites, metal concentrations at S-1 are within the range of natural conditions" [20]. See Table 2 below.

Table 2: Sediment Monitoring Data



Station	Period	Cd (mg/kg)		Cu (mg/kg)		Pb (mg/kg)		Hg (mg/kg)		Zn (mg/kg)	
		Avg	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*
S-1	**Pre-Production (9/1984 - 2/1989) (n=9)**	0.215	0.11	21.8	3.8	7.79	2.1	0.0428	0.01	125.0	7.7
	Production (2/1989 - 12/2010) (n=76)	0.239	0.18	17.63	6.9	8.31	3.8	0.037	0.03	101.44	30.7
	Production (1/2011 - 12/2020) (n=60)	0.121	0.03	14.37	2.2	5.99	0.9	0.028	0.01	99.28	17.8
	Reporting Year 2021 (n=6)	0.11	0.01	15.9	6.2	5.89	0.4	0.0250	0.00	107.8	5.6
S-2	**Pre-Production (9/1984 - 2/1989) (n=9)**	0.265	0.11	14.9	2.6	5.27	2.4	0.0276	0.01	60.5	5.4
	Production (2/1989 - 12/2010) (n=76)	0.169	0.11	11.51	4.4	2.64	1.5	0.014	0.02	44.40	12.7
	Production (1/2011 - 12/2020) (n=60)	0.104	0.04	9.29	1.7	1.76	0.2	0.011	0.01	42.84	9.6
	Reporting Year 2021 (n=6)	0.11	0.01	8.5	0.4	1.62	0.1	0.0112	0.00	41.8	2.9
S-3	**Pre-Production (9/1984 - 2/1989) (n=9)**	0.621	0.28	37.0	9.1	10.03	3.3	0.0669	0.02	127.0	49.8
	Production (2/1989 - 12/2010) (n=76)	0.730	0.33	36.52	10.9	14.56	4.4	0.074	0.03	133.98	35.8
	Production (1/2011 - 12/2020) (n=60)	0.820	0.39	40.22	15.6	15.07	5.6	0.073	0.03	144.48	49.9
	Reporting Year 2021 (n=6)	1.00	0.31	43.6	7.0	17.42	2.7	0.0905	0.01	160.8	28.5

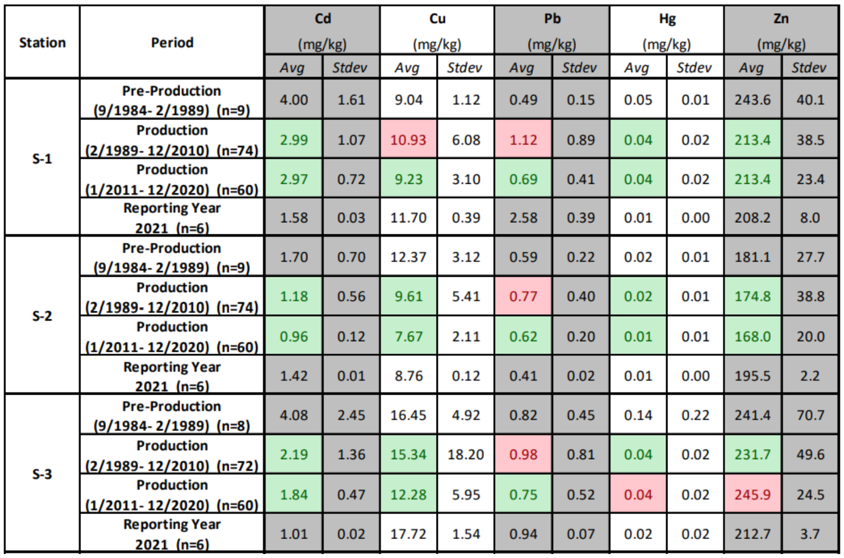
Red shading indicates an increase and green a decrease from the previous period. Non-detects are averaged using half of the MDL.

4.3 Tissue Monitoring

Tissues from polychaete worms (*Nephtys*) and blue mussels (*Mytilus edulis*) are sampled annually at seven locations in Hawk Inlet by Hecla and tested for five specific trace metal parameters including Pb. The objective is to evaluate potential changes in the Hawk Inlet marine environment. All data is on a dry-weight basis.

Tissue sample stations are located near the western point of the Greens Creek delta near wastewater Outfall 002 and near the concentrate loading station. See Plate 3. Additional monitoring sites were added near the concentrate loader after the concentrate spill in 1989.

Table 3: *Nephyts* Monitoring Data



Station	Period	Cd (mg/kg)		Cu (mg/kg)		Pb (mg/kg)		Hg (mg/kg)		Zn (mg/kg)	
		Avg	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*
S-1	Pre-Production (9/1984- 2/1989) (n=9)	4.00	1.61	9.04	1.12	0.49	0.15	0.05	0.01	243.6	40.1
	Production (2/1989- 12/2010) (n=74)	2.99	1.07	10.93	6.08	1.12	0.89	0.04	0.02	213.4	38.5
	Production (1/2011- 12/2020) (n=60)	2.97	0.72	9.23	3.10	0.69	0.41	0.04	0.02	213.4	23.4
	Reporting Year 2021 (n=6)	1.58	0.03	11.70	0.39	2.58	0.39	0.01	0.00	208.2	8.0
S-2	Pre-Production (9/1984- 2/1989) (n=9)	1.70	0.70	12.37	3.12	0.59	0.22	0.02	0.01	181.1	27.7
	Production (2/1989- 12/2010) (n=74)	1.18	0.56	9.61	5.41	0.77	0.40	0.02	0.01	174.8	38.8
	Production (1/2011- 12/2020) (n=60)	0.96	0.12	7.67	2.11	0.62	0.20	0.01	0.01	168.0	20.0
	Reporting Year 2021 (n=6)	1.42	0.01	8.76	0.12	0.41	0.02	0.01	0.00	195.5	2.2
S-3	Pre-Production (9/1984- 2/1989) (n=8)	4.08	2.45	16.45	4.92	0.82	0.45	0.14	0.22	241.4	70.7
	Production (2/1989- 12/2010) (n=72)	2.19	1.36	15.34	18.20	0.98	0.81	0.04	0.02	231.7	49.6
	Production (1/2011- 12/2020) (n=60)	1.84	0.47	12.28	5.95	0.75	0.52	0.04	0.02	245.9	24.5
	Reporting Year 2021 (n=6)	1.01	0.02	17.72	1.54	0.94	0.07	0.02	0.02	212.7	3.7

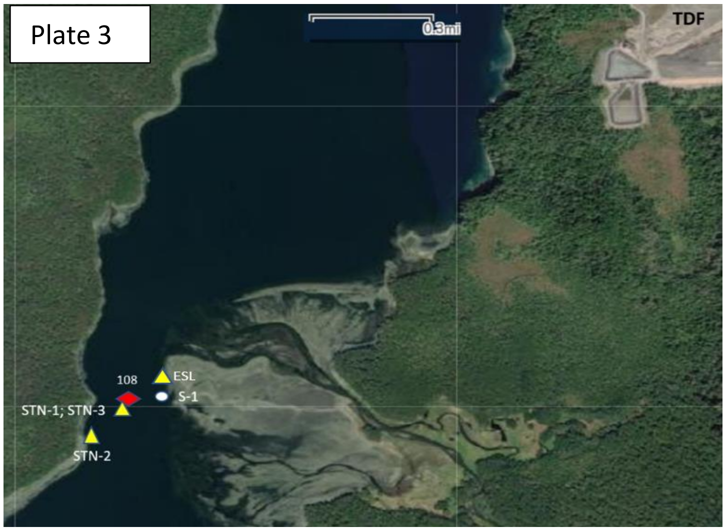
Red shading indicates an increase and green a decrease from the previous period.
Non-detects are averaged using half of the MDL.

Monitoring data indicates that Pb concentrations at the Greens Creek delta (S-1) increased 78% over the pre-production baseline during the first 21 years of production (1989-2010) and have increased by 34% in the 9 years since (2011-2020). Pb concentrations at the natural site in Pile Driver Cove (S-2) have increased 26% over baseline in the first 21 years and 5.0% in the last 9 years of the production period. Pb concentrations in *Nephthys* tissue increased at the head of Hawk Inlet at S-3 by 9% in the first 21 years of mine production and have decreased 8.9% as compared to pre-production baseline concentrations in the last 9 years [20].

Site S-3 is located 4 miles from the Greens Creek delta at the head of Hawk Inlet in a low energy environment with little flushing. Sediments at S-3 are characterized by high organic, possibly reducing and fine texture. In contrast sites S-1 and S-2 are high energy environments with little organic material, varied size and a high rate of flushing. Data from S-3 and S-2 are used to evaluate conditions on the end of the Greens Creek Delta at S-1. The differences in sediment characteristics between the sample sites is not considered.

4.4 Mussel Monitoring.

Mussel tissue is collected annually by Hecla at sites STN-1, 2, 3 and the East Shoal Light (ESL). STN 1, 3 and ESL are close to sediment monitoring station S-1 at the Greens Creek delta and the mixing zone for Outfall 002. See Plate 3. Other samples are collected in the 1989 spill area near the concentrate loader.



Monitoring by Hecla shows that average Pb concentrations in mussel tissues at the East Shoal Light (ESL) on the western point of the Greens Creek delta increased 110% over the pre-production baseline in the first 21 years of production (1989-2010). Average Pb concentration continued to increase 40% over baseline concentrations during the last 9 years of production (2011-2020).

Average Pb concentrations increased at STN-1 by 76% during the first 21 years of production and continued to increase by 47% over pre-production baseline in the last 9 years. At STN-2 average Pb concentrations increased by 128% during the first 21 years of production and continued to increase by 62% over pre-production baseline in the last 9 years. Average Pb concentrations increased at STN-3 by 91% during the first 21 years of production and continued to increase by 21% over pre-production baseline in the last 9 years.

Based on the above data, the 2021 Hawk Inlet Monitoring report concludes: “[Hecla Greens Creek Mining Company] believes that the variation in concentration monitored in organisms near Outfall 002 is natural and that the monitoring program is sufficient for detecting changes” [20].

Table 4: Mussel Monitoring Data

Station	Period	Cd (mg/kg)		Cu (mg/kg)		Pb (mg/kg)		Hg (mg/kg)		Zn (mg/kg)	
		Avg	Stdev	Avg	Stdev	Avg	Stdev	Avg	Stdev	Avg	Stdev
ESL	Pre-Production (9/1984- 2/1989) (n=9)	6.67	1.60	8.16	0.68	0.42	0.11	0.03	0.01	91.40	8.38
	Production (2/1989- 12/2010) (n=46)	6.33	1.91	10.81	15.75	1.43	0.81	0.03	0.02	81.11	18.54
	Production (1/2011- 12/2020) (n=40)	7.11	1.12	9.03	3.02	0.63	0.29	0.03	0.02	89.30	14.94
	Reporting Year 2021 (n=6)	8.31	0.08	8.08	0.07	0.59	0.05	0.02	0.00	92.38	0.66
STN-1	Pre-Production (9/1984 - 12/1989) (n=9)	7.41	1.80	7.96	1.20	0.62	0.41	0.07	0.09	94.92	11.21
	Production (2/1989- 12/2010) (n=46)	7.81	1.80	7.51	1.74	1.38	0.83	0.05	0.06	82.76	14.13
	Production (1/2011- 12/2020) (n=40)	10.75	1.65	8.34	2.40	1.00	0.81	0.04	0.02	109.55	22.54
	Reporting Year 2021 (n=6)	10.87	0.19	8.09	0.57	0.91	0.06	0.05	0.03	96.67	1.56
STN-2	Pre-Production (9/1984 - 12/1989) (n=9)	8.60	3.10	7.71	1.05	0.37	0.19	0.04	0.01	82.36	11.20
	Production (2/1989- 12/2010) (n=46)	8.69	2.53	8.10	3.83	1.69	1.58	0.04	0.02	85.39	18.25
	Production (1/2011- 12/2020) (n=40)	10.06	1.71	8.25	2.95	0.70	0.57	0.04	0.02	101.94	25.15
	Reporting Year 2021 (n=6)	9.94	0.09	8.99	0.14	0.80	0.30	0.04	0.01	90.35	0.91
STN-3	Pre-Production (9/1984 - 12/1989) (n=9)	9.27	3.05	8.50	1.69	0.59	0.21	0.04	0.01	95.73	17.80
	Production (2/1989- 12/2010) (n=46)	8.31	1.88	7.57	2.13	1.58	1.44	0.05	0.08	85.91	15.93
	Production (1/2011- 12/2020) (n=40)	10.67	1.60	7.89	1.90	0.73	0.66	0.04	0.02	102.17	11.44
	Reporting Year 2021 (n=6)	10.02	0.10	8.34	0.12	0.81	0.05	0.03	0.00	99.87	0.62

Red shading indicates an increase and green a decrease from the previous period. Non-detects are averaged using half of the MRL/MDL.

It is difficult to compare results from sites that differ in bottom morphology, type and size of sediment and tidal action. It is also unknown if comparisons can be made between species due to different life spans (time exposed to possibly contaminated sediments). The average life span of *Nephthys* is 3-5 years as compared to mussels that can be expected to live 60-70 years in a healthy habitat.

5.0 Materials and Methods- Present Study

5.1 Summary:

Shells of the butter clam (*Saxidomus gigantea*) were collected from raised marine deposits representing pre-production era conditions and from living organisms representing current conditions, i.e., production-era. Shells were prepared and analyzed for total metals and the stable isotopes of Pb. The ages of the shells were determined by the elevation of the raised beach deposit above sea level, adjusted to Mean Low Tide (MLT) levels for the day and time elevations were taken and compared with the tide gauge operated by NOAA in Juneau, Alaska. [22] The adjusted elevation was then divided by the local rate of isostatic rebound in order to calculate how long ago the organism was alive. Age determination by elevation was augmented by radiometric dating. MLT was used because that is nearest the tide level the clams would have occupied when alive.

Living samples were collected on the Greens Creek Delta to represent current conditions or year 1 on the timeline.

5.2 Field Work

Living samples of the species *Saxidomus gigantea* (butter clam) were collected during low tide in Hawk Inlet at the Greens Creek Delta and in Young Bay. As much as possible, shells of the same general size and weight were selected for laboratory analysis to control for the age of the organism.

The field survey identified and sampled several raised beach deposits (Plate 4.) These occurred in exposed outcrops and in the banks of small streams or in overturned root balls. Raised beach deposits were distinguished from archaeological or cultural midden deposits (shell dumps created by historical human activity) by the cleaner appearance, elevation, visible deposit stratification and the presence of articulated shells. Possible archeological sites were avoided.

Plate 4

Descriptions of the raised beach sites, the presence or lack of stratigraphy, and characteristics of the deposits were recorded. Samples of the strata and any comingled organic material were also collected. Digital photos with a scale were taken to back up field notes. GPS (Garmin GPSmap 76CSx) was used to document sample site locations. A hand level (Northwest Instrument NHL2.5, 2.5x) and tape was used to measure elevation above sea level at the time of the survey. The resulting elevation was corrected to Mean Low Tide for that date and time against the NOAA Tide Gauge in Juneau, Alaska (Station ID: 9452210) [22].

Shell samples were cleaned with a plastic brush and rinsed three times with de-ionized water. Shells were allowed to air dry for 48 hours, weighed, and measured. Samples generally consistent in dimensions and weight were packaged in plastic zip lock bags and sent to analytical laboratories via Fed Ex. Extra samples were taken, cleaned, measured and stored in plastic bags in case of future need.

5.3 Laboratory Analysis

Laboratory analysis for heavy metals and Pb isotopes was conducted by ALS Scandinavia AB laboratories, Luleå branch (ALS). An electronic copy of the QA/QC manual is on file with the

Project Manager. ALS is accredited in accordance with the International Standard ISO/IEC 17025:2005 [23].

To avoid the possibility that the shells may have absorbed Pb from the environment after deposition, the laboratory ablated all shells separately by soaking for 5 minutes in four consecutive soft leaches of 1N HBr and 2N HCl until the final leach was colorless. The weight loss on average was about 70%. The remaining shell was dissolved in 6 N HCl for analysis.

Young Bay sample sites.

Plate 5

5.2.1 Heavy Metals

Total metal concentrations were determined via MC-ICP-MS (Neptune Plus). The stable isotopes of Pb were analyzed via ICP-SFMS (ELEMENT, ThermoScientific). Duplicate analysis of same shell and duplicate shells from the same strata were analyzed at a rate of at least 20%.

5.3.2 Radiocarbon Age of Shells.

Separate shells from the same strata were sent to Beta Analytic Testing Laboratory in Mami, Florida (ISO/IEC 17025:2017) for radiocarbon dating using Accelerator Mass Spectrometry (AMS) via a tandem electrostatic accelerator (Thermo-Finnegan Delta Plus). Radiocarbon years were adjusted to calendar years according to the High Probability Density Range Method: Marine 20 for this longitude and latitude. Calendar ages are accurate to +/- 30 years. Radiocarbon dating was used to verify dating derived by using elevation.

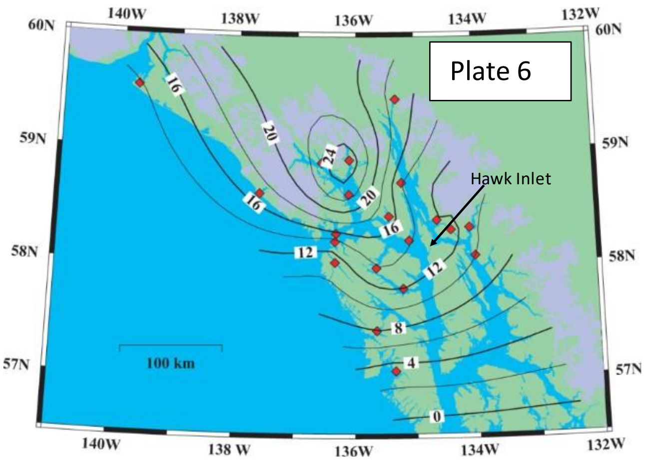
5.3.3 Age Determination of Shells

The shells of living specimens collected on the Greens Creek Delta in Hawk Inlet and in Young Bay represent the Pb concentrations during the production era of the Greens Creek Mine.

The age of the shells for the raised beach deposits were determined by measuring the elevation above Mean Low Tide (MLT) multiplied by the rate of uplift per year in the region.

It has been determined that the rate of isostatic rebound in the area of Hawk Inlet is 12.0mm/year. See Plate 6. This is countered by a sea level rise due to melting glaciers of 2.2mm/year. Age of the raised beach deposits then becomes the elevation above MLT in mm divided by 9.8mm/year [24].

Age determined by elevation in the Hawk Inlet samples assumes an accuracy of +/- 12 inches (305mm) in elevation as determination by hand level. Given the 9.8mm/year rate of uplift, this would indicate an accuracy of +/- 31 years, comparable to the +/- 30 years range of accuracy for radiocarbon dating.



Negative sea level rates from tide gauge data. Contour interval is 2 mm yr $^{-1}$. Red diamonds indicate tide gauge sites. Glaciers and icefields are shown in light purple. [15]

6. Results and Discussion

6.1 Timeline

Overall, dating by elevation was comparable to the radiometric method but only two direct comparisons could be made; Sites 10 and 12 (Table 2). Site 10 results are essentially the same between the two methods. At Site 12, radiometric dating resulted in a slightly lower (14%) age date than that determined by elevation. No radiocarbon dating was done on the raised beach samples collected from Young Bay.

All samples from raised marine beach deposits in Hawk Inlet and Young Bay were dated from prior to the Greens Creek mine production period. Hawk Inlet samples ranged from 410ybp to 1100ybp. Information from the midden shell provided by the Forest Service (#11 Test Pit 2, Level 3) did not include the location of the midden deposit, so age by elevation could not be determined. The midden shells were the oldest of all samples, with a radiocarbon date of around 2100 ybp Young Bay raised beach deposits ranged from 330-650ybp.

Table 5: Location, elevation, and clam age at sample sites Age Determination

Site #	Location	Longitude/Latitude	Elevation (mm)	Age as Determined by Elevation-mm/9.8mm/y (ybp)	Radiometric age (ybp)
Midden	Hawk Inlet				2130
Site 1	Hawk Inlet	N58.09706 W134.76532	3988	410	
Site 8	Hawk Inlet	N58.09936 W134.76111	10064	1030	
Site 9	Hawk Inlet	N58.10020 W134.76196	9652	980	
Site 10	Hawk Inlet	N58.10012 W134.76196	9881	1000	1020
Site 11	Hawk Inlet	N58.10012 W134.76196	10168	1040	
Site 12	Hawk Inlet	N58.10012 W134.76196	10777	1100	960
Site 1	Young Bay	N58.16959 W134.70386	3190	330	
Site 2	Young Bay	N58.16959 W134.70404	3632	370	
Site 3	Young Bay	N.58.17038 W134.70311	6345	650	

6.2. Changes in Lead Concentrations

Changes in Pb concentration were calculated by the relative percent difference in the average Pb concentrations between pre-production and production era shells and between Hawk Inlet and Young Bay shells based on the formula:

$$\mathrm{RPD}=(x_2 - x_1)|/((x_2 + x_1)/2)\mathrm{x}100$$

Young Bay samples from the pre-production period show an average Pb concentration of 250ug/kg (n=5) compared to an average Pb concentration of 230ug/kg (n=11) in Hawk Inlet. The standard deviation of Pb concentration in the pre-productions samples in Hawk Inlet is 36ug/kg and in Young Bay 52ug/kg indicating Pb concentrations are measurably the same prior to mine activities on both sides of Admiralty Island.

The pre-production levels of lead from Young Bay and Hawk Inlet were also compared using an unpaired *t*-test.

$$t = \frac{m - \mu}{s/\sqrt{n}}$$

t = Student's t-test
m = mean
μ = theoretical value
s = standard deviation
n = variable set size

The results; t =0.7135. The 2 tailed P value is 0.4837 with a standard error of difference of 30.5. By conventional criteria, the difference between pre-production Pb levels between Young Bay and Hawk Inlet are not statistically significant.

The mean Pb levels in living shells (production era) had an average concentration of 634ug/kg (n=6), which is significantly higher than the pre-production clams (227ug/kg (n=11)). Thus, modern shells are on average 2.8-fold higher in Pb concentration than their pre-production ancestors. This represents an overall 95% increase in Pb concentrations over time in the area of the Greens Creek Delta.

Using the t-test as above, the difference between Hawk Inlet pre-production and production era Pb levels is extremely statistically significant by conventional criteria. The test gives a t = 7.996, P value of <0.0001 with a standard error of difference of 51.05. This indicates a significant increase in Pb levels in Hawk Inlet during the production era.

Pb concentrations also increased in clam shells from pre-production to the production era in Young Bay. Shells collected from raised beach deposits had a mean Pb concentration of 254.2ug/kg (n=6) compared to living specimens with a mean Pb concentration of 384.8ug/kg (n=5). This indicates an approximately 40% increase in Pb between pre-production and the production era at Young Bay.

Applying the *t*-test as above, the difference between pre-production and production era Pb levels in Young Bay are not considered statistically significant (*t* = 1.6756, P value = 0.1324 with a standard error of difference of 81.4). This t-test may be overly influenced by one result. The average of 4 out of 5 of the Pb concentrations in living shells was 456ug/kg. The 5th result was 99.4ug/kg Pb. Removing this possible low outlier results in a significant statical difference between pre-production and production era Pb concentrations in Young Bay (*t* = 4.6989. P value =0.0022 with a standard error of difference of 44.2). These data indicate that Pb levels also increased in Young Bay, but to a much lesser extent than in Hawk Inlet.

Levels of Pb in the marine environment in both Young Bay and Hawk Inlet started out roughly the same (within the range of variance) during the pre-mine production era; average of 227ug/kg in Hawk Inlet versus 255ug/kg in Young Bay. Pb concentrations in both bays increased in recent times. The rate of increase in Hawk Inlet is approximately 50% greater (41% compared to 95%) than in Young Bay.

Although an effort was made to collect clams of the same approximate size (age class), living specimens collected in Young Bay averaged almost 50% larger (71cm^2) versus Hawk Inlet (40cm^2) clams and therefore are presumably older assuming similar rates of growth. Older individuals may have had more time to deposit environmental Pb into the shells. It is unknown what contributes to the difference in butter clam size/age between Hawk Inlet and Young Bay. Factors may include differences in habitat, differential harvesting, predation pressure or environmental contaminants affecting the health of the organism. Whatever the reason, the larger (and presumably older) clam shells in Young Bay would likely have higher Pb levels due to longer accumulation times versus the younger individuals collected in Hawk Inlet. The testing of older individuals in Young Bay may artificially skew the results toward higher levels of Pb when compared to the smaller shells available in Hawk Inlet.

Table 6: Quality Control

Location: Historical or Living	Site #	Replicate	Pb Conc. (ug/kg)	Type of Replicate: Analytical or Shell*	Standard Error of Mean	RPD (%)
Hawk Inlet Historical	1	1	320.5	Analytical	51	38
		2	217.8			
Hawk Inlet Historical	8	1	294	Analytical	11	7.6
		2	272.4			
Hawk Inlet Historical	8	1#	283.2#	Shell	45	38
		2	193.6			
Hawk Inlet Historical	9	1	233	Shell	24	23
		2	185			
Hawk Inlet Historical	10	1	320.5	Shell	51	38
		2	217.8			
Hawk Inlet Historical	11	1	195.6	Shell	4	4.2
		2	187.5			
Hawk Inlet Historical	Midden	1	249.4	Analytical	1.7	1.4
		2	252.8			
Hawk Inlet Living	1	1	604.4	Analytical	27	10
		2	545			
Hawk Inlet Living	2	1	597.1	Shell	69	26
		2	458.6			
Hawk Inlet Living	4	1	657.9	Analytical	67	23
		2	524.1			
Young Bay Living	1	1	448.6	Analytical	20	9.2
		2	409.1			
Young Bay Historical	2	1	223.2	Analytical	6	5.2
		2	235.1			
Tailings	S3,P1 Area	1	5284000	Analytical	410,000	14
		2	6104000			

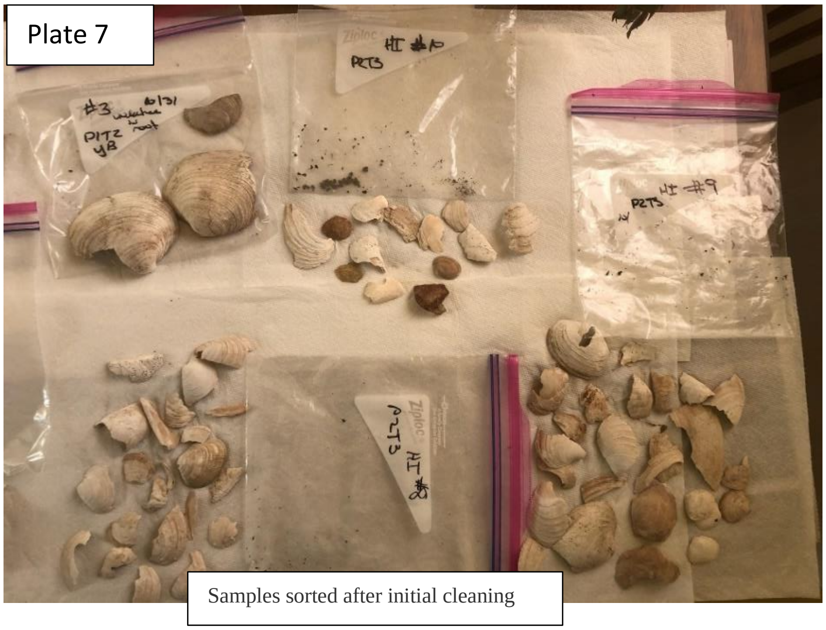
*Analytical=duplicate analysis same shell. Shell=-duplicate shell from same site

Replicate value = average of Analytical results

It is unlikely that fugitive dust would be a source of Pb in the living clams in Young Bay. Young Bay lies north and east of the tailing's facility. The predominant wind direction during the dry, dusty months are from the north/northeast, away from the direction of Young Bay. The expected fugitive dust loading region is to the south of the tailing's facility [25].

Pb levels in the environment have been increasing world-wide. Beginning in 1922, tetraethyl Pb was added to motor vehicle fuels to improve engine performance. By the 1970's almost all motor vehicle fuel contained Pb. By then the consumption of gasoline Pb exceeded 270,000 tonnes (1 tonne is equivalent to 1.1 US tons) in the United States and 375,000 tonnes worldwide [26]. Only in 2021 was Pb fully removed from fuels worldwide.

Plate 7



Samples sorted after initial cleaning

Leaded fuels have been identified as a prevalent source of environmental Pb contamination during the 20th century and may account for some of the increase in Pb in both bays [27].

This study shows the concentration of Pb in the environment remained relatively consistent throughout the pre-production era in both locations. Pb levels in both Hawk Inlet and Young Bay increased during the production era of the Greens Creek Mine. Young Bay Pb concentrations increased 41% while Pb in Hawk Inlet increased 95% between pre-production and production periods.

The recent increase in Pb in the environment in Hawk Inlet does not support the hypothesis of natural erosion as the source. Natural erosion occurs at basically the same rate over time and produces a monotonic trend. There are no known factors (e.g., large land sliding, increased rainfall) in this part of Admiralty Island that would have led to any increase in natural erosion.

Hawk Inlet Pb concentrations remained relatively stable for about 1700 years, then increased dramatically only recently. See Chart 1. The '0' year before present (ybp) on the time scale is present day (2020) levels.

Young Bay Pb concentrations have increased 41% (average of 254ug/kg to an average of 385ug/kg) over the historic baseline to the present day.

Chart 1

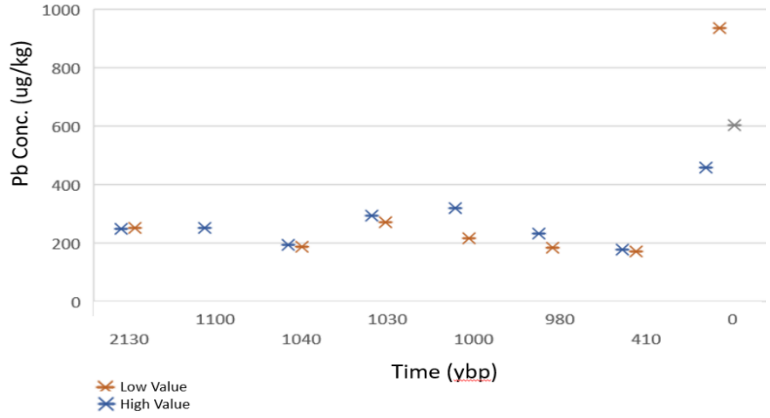
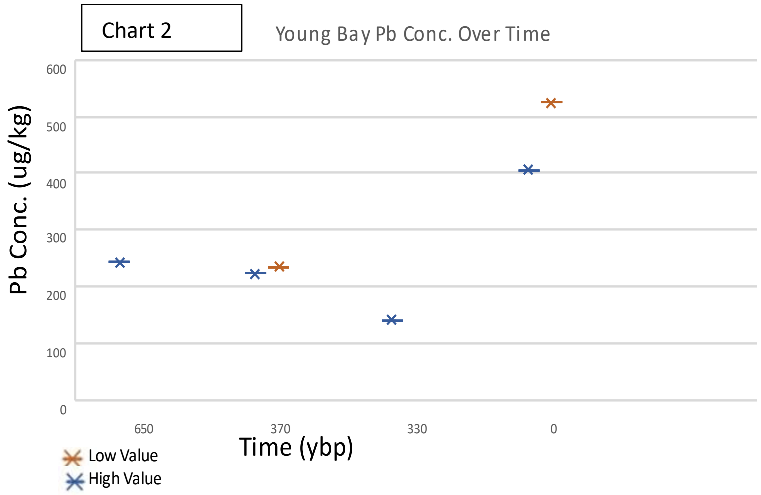


Chart 2



Hawk Inlet Pb concentrations have increased 95% (an average of 227ug/kg compared to an average 635ug/kg) over the historic baseline to the present day.

If leaded fuels contributed to Pb concentrations in both Youngs Bay and Hawk Inlet equally, then Hawk Inlet experienced an estimated 54% increase (95% increase in Hawk Inlet minus a 41% increase in Young Bay) due to another source.

6.3 Stable Isotope Analysis

Ratios of the Pb isotopes were measured and calculated for 206/204, 207/204, 208/204, 207/206, and 208/209. Only one sample of tailings was tested, a composite of 10 grab samples from the active Stage 3 Phase 1 area of the TDF.

Additional isotope ratio data for the tailings was obtained from a previous study of the Greens Creek deposit [28]. The median of 81 results from this study was combined with the measured isotopes of the tailings and used for calculating the differences of isotope ratios measured in the clam shells. This report did not contain data on the ratios 207/206 and 208/207. In addition to the median of all 81reported results, Greens Creek Galena and Kennecott-Rand deposits were averaged and used in the comparison since these deposits have been mined during the production era and are known to be present in the tailings.

Comparisons were made between the pre-production historic ratios and the ratios measured in production era shells from both bays. Relative percent difference was calculated based on the median of each sample set and compared to the median ratios of the tailings. See Table 6, Stable Isotope Comparison by % relative percent difference (RPD).

Ratios of $^{206/207}$Pb show the largest difference between pre-production Pb in both bays and the modern mining era Pb in Young Bay. The smallest measured difference in Pb is between the tailings and production era Pb in Hawk Inlet shells. In Hawk Inlet, there is a greater than 1% (1.07%) difference between $^{206/204}$Pb in pre-production era shells versus production-era shells. The pre-mining era shells also are greater than 1% (1.21%) different in the $^{206/204}$Pb ratio than in the sample of the tailings. In contrast, there is only a 0.014% difference in the $^{206/204}$Pb ratio between production-era shells and the tailings.

In Young Bay there is a smaller difference of 0.31% in $^{206/204}$Pb ratios observed between the pre-production era shells and production era shells. A larger difference in $^{206/204}$ Pb ratios was also observed between the Young Bay shells and the tailings. Average pre-production era shells and tailings were 2.01% different as compared to the tailings. The mining-era shells in Young Bay averaged 1.7% different that the tailings.

This strongly suggests that the source Pb in Hawk Inlet during the mining production era is more related to the tailings than either the Pb measured prior to mine activities in Hawk Inlet and any Pb measured in Young Bay.

Table 6: Stable Isotope Comparison by relative percent difference (RPD).

HI= Hawk Inlet; YB= Young Bay.

Table 7 Comparison RPD (%)	Lead 206/204	Lead 207/206	Lead 208/207	Lead 207/204	Lead 208/204
HI Pre-Production shells/Production shells	1.07	0.78	0.07	0.2	0.04
HI Pre-Production shells/Tailings	1.08	1.15	0.02	0.006	0.018
HI Production shells/Tailings	0.014	0.37	0.08	0.184	0.061
YB Pre-Production shells/Production shells	0.31	0.1	0.11	0.09	0.22
YB Pre-Production shells/Tailings	1.88	1.91	0.38	0.137	0.25
YB Production shells/Tailings	1.67	1.87	0.28	0.226	0.025

Overall, the stable isotope data for the tailings and in all clam shells in Young Bay and Hawk Inlet show no statically significant differences using a standard unpaired *t*-test. This indicates that the Pb present in the shells comes from similar mineral geology contributing to Pb in both bays.

The uplands in Young Bay and Hawk Inlet both host similar mineralized rocks. Both are drained by freshwater inputs into their respective marine environments. Given the large difference in Pb concentrations in Hawk Inlet production-era shells as compared to Young Bay production-era shells, this finding conflicts with the assumption that natural erosion as a source in Hawk Inlet.

To account for the elevated levels of Pb in Hawk Inlet as opposed to Young Bay, we must identify other possible pathways and various points of entry of Pb into Hawk Inlet.

Table 8 Isotope Ratio QC

Hawk Inlet Historical n=6	Lead 206/204	Lead 207/206	Lead 208/207	Lead 207/204	Lead 208/204
Average	18.8645	0.87295	2.460627	15.6045	38.40142
Average Deviation	0.0208	0.0009	0.0003	0.0062	0.0155
Median	18.864	0.8271	2.461	15.6062	38.3973
Skew	0.7935	0.4281	0.2316	-3	3
Hawk Inlet Living n=6	Lead 206/204	Lead 207/206	Lead 208/207	Lead 207/204	Lead 208/204
Average	18.708	0.8336	2.4734	15.5955	38.5737
Average Deviation	0.065	0.0003	0.025	0.0596	0.3056
Median	18.6635	0.8336	2.4589	15.5757	38.3808
Skew	1.0322	0.0315	2.447	0.806	2.9931
Youngs Bay Historical n=6	Lead 206/204	Lead 207/206	Lead 208/207	Lead 207/204	Lead 208/204
Average	18.934	0.8236	2.4666	15.5918	38.5131
Average Deviation	0.1577	0.006	0.007	0.1048	0.1983
Median	19.0155	0.8204	2.4702	15.5831	38.5001
Skew	-2.4001	2.1728	2.3686	-2.9996	2.9979
Youngs Bay Living n=5	Lead 206/204	Lead 207/206	Lead 208/207	Lead 207/204	Lead 208/204
Average	18.9058	0.8237	2.4656	15.5714	38.3935
Average Deviation	0.09512	0.0038	0.0028	0.008	0.05
Median	18.957	0.8212	2.4675	15.5692	38.4137
Skew	-2.2044	2.1494	1.7872	-2.8284	-2.8283
Tailings/Ore Deposit n=5*	Lead 206/204	Lead 207/206	Lead 208/207	Lead 207/204	Lead 208/204
Average	18.6374			15.6049	38.514
Average Deviation	0.0319			0.0214	0.157
Median	18.6374			15.594	38.3882
Skew	-2.8282			-2.8282	2.8274

7. *Points of Entry of Lead into Hawk Inlet.*

We examined all available data on possible sources of Pb entering into the environment in Hawk Inlet in order to account for the elevated levels.

7.1 Historic Mining: Alaska Empire

The Alaska Empire Mine operated from 1919 until 1946 in the uplands above the northwest side of Hawk Inlet. The mine site contains exposed waste rock, tailings, as well the remains of some equipment. The location is drained by a small unnamed creek directly into Hawk Inlet. Data is available on the concentrations of various contaminants in water, sediment and tissues.

7.1.1 Empire Mine Water Results.

The USFS analyzed water samples for cadmium, copper, lead, mercury, and zinc from eight freshwater stations at Empire Mine in September of 2014. Five samples were collected at the upper site (stations US002W, US003W, US001W, US005W, and US004W) and three samples at the lower site (stations LS002W, LS001W, and LS003W). Pb was not detected in any samples [21].

7.1.2 Empire Mine Tissue Results.

Tissue samples were collected by the Alaska Department of Fish and Game from two clams and one mussel where the fresh water tributary enters Hawk Inlet. The average of Pb concentration measured in the bivalves is 0.40mg/kg (400ug/kg). Tissue samples were also collected and analyzed in ten Dolly Varden Char from the tributary. All Pb results in Dolly Varden Char were non-detect with a detection limit of 0.05 mg/kg (50ug/kg) [21].

7.1.3 Empire Mine Sediments Results.

Sediment samples were collected at four stations by ADEC in 2014 and analyzed for Pb along with other metals. Station 1 is located at the lower camp on the mainstream about 200 to 250 ft upstream of Hawk Inlet. Station 6 is a marine site in intertidal sediment. Stations 11 and 14 are freshwater sites at the upper camp. Station 11 is below two piles of tailings at the upper camp and station 14 is located above the mine workings. Station 14 is upgradient of all potential impacts of past mining activities and could be considered a background site. In addition, sediment samples were collected at seven stations by the USFS in 2014 and analyzed for Pb, among other metals.

The average Pb concentration from all stations was 10.8mg/kg, with the highest measured level of 71.7mg/kg at Station US003S located about 1.1 miles uphill from Hawk Inlet. Station US003S is the only station not located in the mainstream of the tributary and is adjacent to a bog (Canyon Bog), a potentially reducing environment that may contribute to metal dissolution and mobility. The average results of all sediment sites (n=6) at the confluence of the fresh water and Hawk Inlet are 9.5mg/kg (9,500ug/kg) ranging from 3.4mg/kg 13.4mg/kg [21].

The sediment results associated with the Alaska Empire Mine do not mirror the results of water testing at the site. It would appear that the Pb present, measured as total Pb, is not in a mobile or dissolved form. The marine sediments downstream from the Alaskan Empire could be a minor source of the Pb concentrations observed on the Greens Creek delta 5.5 miles to the south due to some unknown method of transport.

7.2 Waste Water Outfalls

Two outfalls, designated 002 and 003, are permitted to discharge directly into Hawk Inlet under APDES permit #AK0043206. Outfall 003 is a stormwater outfall; however, as of 2011, a collection system was installed that routes the majority of the stormwater to water treatment to be discharged through Outfall 002.

Water column sampling is performed in the receiving waters of Hawk Inlet at ambient stations 106, 107, and 108 monitor Outfall 002 every 3 months by Hecla at a depth of 5 feet. Only Station 108 is proximal to the mixing zone. The vast majority of Pb concentrations measured in the vicinity of the 002 are non-detect at a detection limit of 0.02 ug/L. All water quality data at Outfall 002 meet applicable permit limits. The highest Pb recorded in Hawk Inlet associated with Outfall 002 during the 2020 water year was 0.072ug/L [21].

The 002 Outfall does not appear to be a source of Pb loading in Hawk Inlet.

7.3 Storm Water

There are fourteen storm water outfalls into fresh waters that eventually drain into Hawk Inlet. Most of the monitoring stations associated with these outfalls collect data from upstream of the outfall for comparison and therefore provide information on naturogenic inputs of Pb into Hawk Inlet. The mine also tests the effluent and receiving water downstream of the outfalls that gives information as to possible anthropogenic sources due to mine operations. These outfalls are tested after storm events, spring run-off or snow melt. Receiving water monitoring is conducted semiannually by Hecla at the same time as each associated outfall is sampled. Pb is measured as total recoverable. Only Outfall 003 discharges directly into Hawk Inlet.

7.3.1 Naturogenic Sources from Stormwater Data

The most recent report (water year 2021) shows that the surface waters with upstream monitoring averaged 0.006mg/L (6.0ug/L) Pb. Seven of the twelve sites exceeded the Alaska chronic Pb freshwater criteria adjusted for hardness. These sites averaged 0.009 mg/L (9.0ug/L)

Pb. There were no reported exceedances of the acute fresh-water criteria for Pb [29]. It must be noted that each receiving water drains a different size watershed, so a direct average of Pb concentrations across all watersheds only gives general information about total Pb input from the uplands.

Data going back to 2006 shows that changes in up-stream Pb levels generally track downstream concentrations. These freshwater inputs do not appear to be a significant natural contributor of Pb to Hawk Inlet.

7.3.1 Anthropogenic Sources from Stormwater data.

APDES Permit AK-0043206 requires Hecla to monitoring the receiving water directly upstream and downstream of where each stormwater outfall enters the receiving water. Receiving water monitoring is conducted semiannually and at the same time (within three hours) as each associated outfall. Samples are collected during the spring runoff or snow-melt in June and during rainfall events in September. Because of the time required to visit all ten storm water outfalls and associated receiving water sites, monitoring often occurs over multiple days and potentially during separate storm events. Pb is measured as Total Recoverable rather than dissolved. It is compared to the hardness-adjusted fresh water chronic criteria.

Of the 10 Stormwater outfalls monitored in 2021, four show exceedances of water quality criteria. In September of 2021, Storm Water Outfall 003 draining directly into Hawk Inlet Pb was measured at 5.95ug/l over the hardness adjusted chronic fresh water criteria of 3.18ug/l. The receiving water remained below the water quality criteria for Pb.

Outfall 005.2 results for June of 2021 were 5.29ug/l Pb and in September 10.5ug/l. Both were above the hardness corrected chronic fresh water criteria of 0.6ug/l and 1.02ug/l respectively. The receiving water remained below the criteria for both months.

Storm Water Outfall 005.3 – Site E. the concentrations of Pb in stormwater exceed chronic criteria for fresh water (3.97ug/l) in the June with a Pb concentration of 5.07ug/l. The receiving water for June also exceeded criteria both in the upstream sample (5.52ug/l) and downstream sample (4.06ug/l). The applicable water quality criteria for Pb are 1.47 and 1.38ug/l respectively. In September, the storm water Pb concentration of 9.08ug/l exceeded the chronic fresh water criteria of 6.87ug/l for Pb. In September the receiving water upstream and downstream remained below the Pb criteria.

Storm Water Outfall 005.5 located at the 7.8 Mile B-Road Culvert. Pb concentrations in samples collected from this location measured 271ug/l in June, exceeding the 2.74ug/l chronic freshwater criteria. Upstream of the culvert, Pb concentration was measured at 2.19ug/l versus the water quality criteria of 0.93ug/l. Downstream of the culvert, Pb concentrations were measured at 2.87ug/l versus the water quality criteria of 1.12ug/l. In September of 2021, Pb was measured at 5440ug/l as compared to the hardness adjusted criteria of 18.58ug/l. Both upstream and downstream sites remained below the applicable water quality criteria in September. Discharge from this culvert is to a forested hillside, approximately 200 feet from Greens Creek. Due to low flows (less than 10 gpm), the drainage infiltrates into the forest duff and does not enter into Greens Creek and therefore does not add to Pb loading in Hawk Inlet [30].

It appears from this data that storm water effluent could be a minor source of anthropogenic Pb into Hawk Inlet.

7.4 Freshwater Tributaries to Hawk Inlet

7.4.1 Water Quality Data

There are nine freshwater monitoring stations (stations 6, 9, 46, 48, 49, 54, 60, 61, and 62) on tributaries flowing into Hawk Inlet. They are tested for cadmium, copper, lead, mercury, and zinc by Hecla. The monitoring schedule varies. The hardness-based aquatic life chronic freshwater criteria are calculated based on the average hardness at each station. The only station showing exceedances in Pb was Station 9 on Tributary Creek approximately 1 mile downstream and south of the TDF. Tributary Creek flows into Zinc Creek which joins Greens Creek just above the Greens Creek Delta and discharges to Hawk Inlet. Site 9 shows eleven exceedances (out of 55 samples, i.e., 20%) of the Pb water quality criterion of 0.76 µg/L from 2006 to water year 2020. The most recent exceedance was in 2020 measured at 0.49ug/L Pb. [31]. Site 9 began exceeding the Alaska freshwater chronic criteria in June of 2018 [31].

In 2022, the Final Integrated Report issued by the State of Alaska listed just under one mile of Tributary Creek as a category 4B impaired waterbody due to lead contamination. Hecla acknowledged that fugitive dust from the TDF may be a potential source contributing to the dissolved lead concentrations detected in Tributary Creek [37]. It appears that the Pb measured in Tributary Creek is anthropogenic and not natural.

7.4.2 Fresh Water Tissue Data

Hecla operates four sampling stations in tributaries to Hawk Inlet collecting fish tissue data on Dolly Varden char. There are no EPA recommended values for Pb in freshwater fish tissue for comparison. The average Pb (total) concentration in fish tissues at these stations is 0.71 mg/kg dry weight [32].

7.4.3 Fresh Water Sediment Data

Sediments from three freshwater stations in tributaries to Hawk Inlet were collected and analyzed by ADF&G in July of 2013. Station 9 is in lower Tributary Creek, Station 48 is in upper Greens Creek, and Station 54 is in lower Greens Creek (below D-pond). Only one sample was collected at each station. The average Pb concentration of all three stations is 18.1mg/kg total lead. The highest observation was at Site 54 with a value of 29.8mg/kg Pb. This roughly corresponds with the storm water data observations at this location.

Alaska does not have numeric sediment quality criteria for Pb. Sediment data from these stations was compared to the freshwater NOAA SQuiRT screening values that look for adverse effects on benthic organisms. None exceeded screening levels for Pb [31].

Based on available data from the Fresh Water Monitoring Program it appears that there is minimal contribution of lead to Hawk Inlet from fresh water tributaries.

7.5 Contaminated Site (Concentrate Spill Area) Data

In May 1989, the first attempt to load a barge with ore concentrate resulted in a spill of approximately 1,000 pounds of concentrate into Hawk Inlet. A suction dredge contractor removed approximately 550 cubic yards of concentrate and sediment from the site in 1994. A sample site (Site S-4) was located under the loading facility and has data prior to the spill. S-4 is sampled annually. After the spill, two additional sites, Sites S-5N and S-5S were established. Sites S-5N and S5S are sampled by Hecla every five years. These sites are also thought to be influenced by the old cannery operation. Data are collected for sediment and tissues (benthic worm *Nephthys sp*.).

7.5.1 Sediment Data

Sediment is collected by Hecla according to requirements in the APDES permit. All samples are processed according to the Puget Sound Estuary Program (PSEP) protocols as updated by Washington Department of Ecology. There is no further information available as to the method of sampling used to collect the sediment or sediment size or other characteristics of the sediment itself. Sediment size can largely determine the concentrations measured because small particles have much higher surface area and will have higher metal concentrations compared with larger sediment particles. Absent the particle size data, the measured metal concentrations at these sites may be of limited use.

The pre-production, post-cannery (9/84-9/89) averages show 53.8mg/kg Pb at Site S-4. Production era (2/89-2019) averages at S-4 are 57.8mg/kg Pb, or slightly above the pre-production averages. The latest data at S-4 in 2020 measured 14.7mg/kg Pb [31].

Only production era data is available for Sites S-5N and S-5S within the spill area Production era averages for Pb are 715.4 mg/kg and 341.9 mg/kg respectively [33].

7.5.2 Tissue Data

Tissue is data is only available at Site S-4. Pre-production era averages (n=2) for total Pb in *Nephthys sp*. is 4.16mg/kg. Production era levels have risen slightly to an average 6.85mg/kg Pb. The latest 2020-year result is 3.22mg/kg total Pb [31].

It is likely that elevated (as compared with other sites in Hawk Inlet) Pb levels in sediments and tissue at Site S-4 during the pre-production period were due to cannery operations that existed at the site for 66 years prior to mine production. The presence of Pb acid batteries from cannery operations has been observed in the area [31]. The vast majority of Pb within the spill area is anthropogenic whether due to the concentrate spill or cannery.

Lead mobility in a marine environment is variable. Lead is highly mobile and bioavailable in its ionic form (dissolved), only slightly mobile and bioavailable when bound to organic complexes, or of very limited mobility and availability when attached to solid particles of clay or organic material. There is no data as to the form of Pb in this area, but Pb from ore concentrate and batteries would not likely exist in a bioavailable dissolved organic form, but it can be assumed that Pb may exist in all three forms within the impaired area.

An examination of the likelihood that the sediments contaminated by the spill and cannery could be the source of the measured recent increase in lead in the environment on the Greens Creek delta would have to consider a method of transport.

The contaminated area is approximately three miles north from the location on the Greens Creek delta where clams were collected for this study and for the pre-production species diversity and population baseline studies. As noted above, dissolved Pb does not appear in the water monitoring data for Outfall 002 located just off the end of the Greens Creek delta.

The spill area is located on the east side of Hawk Inlet and north of the Greens Creek delta. Information from dye studies indicate that water flows into the inlet along the east side northward away from the delta and towards the spill site. "Incoming tide (flood) "occurs predominantly along the eastern side of the Inlet. . . . and currents on the eastern shore tend to be directed northward during all phases of the tide" [1].

Dispersion dye studies were also used to examine the length of residence and the rate of flushing of substances released into Hawk Inlet. These studies concluded that, overall, Hawk Inlet has a relatively good exchange of tidal water [1].

It is unlikely that physical transport of contaminated sediments or dissolved Pb from the spill area would be influencing levels of Pb on the Greens Creek delta given that the prevailing currents run away from the Greens Creek delta and towards the site of the 1989 spill.

7.6 Fugitive Dust.

The mine stores tailings (waste product from froth-flotation concentration) on land in a dry-stack tailings disposal facility (TDF) located less than 500 feet east of Hawk Inlet. See Plate 1. As of 2020, the TDF contains about 5.44 million cubic yards of material or 10,066,072 tons [34]. Analysis by Friends of Admiralty shows the tailings contain about 0.53% total Pb by weight or about 53,000 tons. The Environmental Impact Study conducted by the U.S. Forest Service predict over 100 tons of fugitive dust per year are expected to exit the TDF under the current operating plan, even with all mitigation measures successfully implemented [35]. Hecla's dust monitoring program does not extend beyond the foot print of the TDF. There is no data on dust amounts entering the Monument, wilderness area or marine environment.

The Greens Creek intertidal delta is a 41.3-hectare (100 acres) area of alluvial soils approximately one mile southwest of the TDF. Fugitive dust is considered a nonpoint source air pollutant, because it consists of small airborne particles that do not originate from a singular location point. Fugitive dust has been monitored by the mining company since 2011. Monitoring indicates Pb loading was most prevalent at collection stations west of the TDF from 2011 to 2014 and more south and southeast of the TDF toward the Greens Creek delta since 2015-2021 [25]. Alluvial soils of the type found on the Greens Creek delta may act as collectors and reservoirs of airborne metal contamination such as Pb due to the daily tides that alternately expose and inundate the area. The delta also is high in organic material that may promote binding and methylation of Pb into more bioavailable forms. Once absorbed in the alluvium, Pb could be integrated temporally and spatially through erosional and depositional processes and become available to organisms living in these sediments [36].

Below is Table 9: Summary of Lead Loading at Dust Monitoring Stations Surrounding the TDF. Columns indicate cardinal directions from the TDF. Annual values are based on collections from the monitoring devises at variable frequencies, seasonally dependent over the year. The collectors are washed and filtered through a pre-weighed 2.5-micron, 90 mm quartz filter. The filters are dried, weighed, and analyzed for total Pb.

For reporting year 2021, the south collector had the highest lead load of 1,860 µg/m2 /yr.

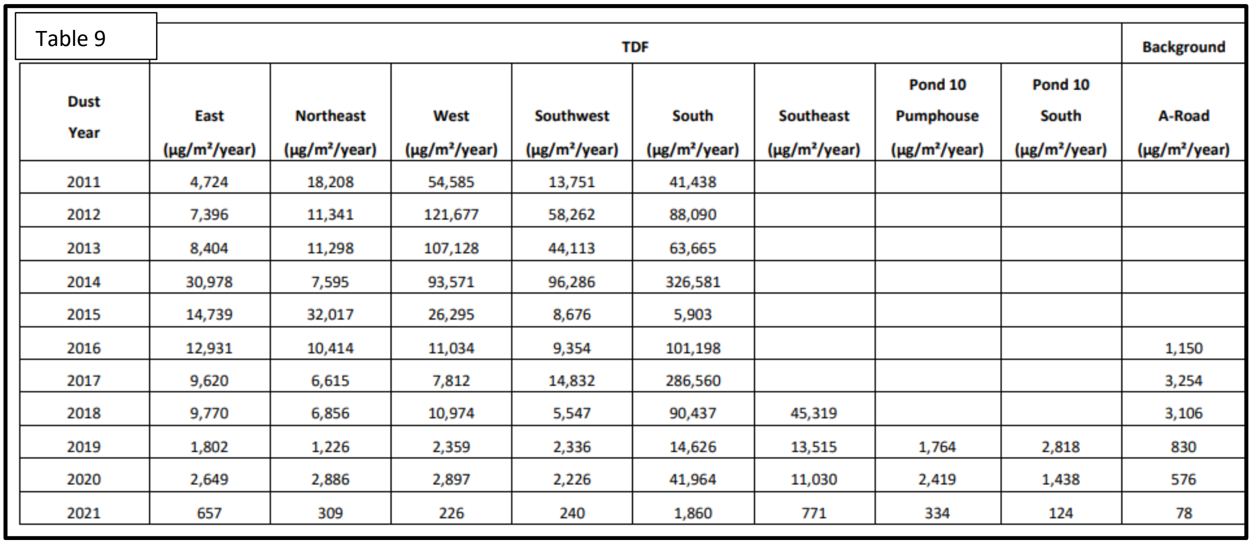


Table 9	TDF								Background
Dust Year	East (µg/m²/year)	Northeast (µg/m²/year)	West (µg/m²/year)	Southwest (µg/m²/year)	South (µg/m²/year)	Southeast (µg/m²/year)	Pond 10 Pumphouse (µg/m²/year)	Pond 10 South (µg/m²/year)	A-Road (µg/m²/year)
2011	4,724	18,208	54,585	13,751	41,438				
2012	7,396	11,341	121,677	58,262	88,090				
2013	8,404	11,298	107,128	44,113	63,665				
2014	30,978	7,595	93,571	96,286	326,581				
2015	14,739	32,017	26,295	8,676	5,903				
2016	12,931	10,414	11,034	9,354	101,198				1,150
2017	9,620	6,615	7,812	14,832	286,560				3,254
2018	9,770	6,856	10,974	5,547	90,437	45,319			3,106
2019	1,802	1,226	2,359	2,336	14,626	13,515	1,764	2,818	830
2020	2,649	2,886	2,897	2,226	41,964	11,030	2,419	1,438	576
2021	657	309	226	240	1,860	771	334	124	78

H1 2021 Biannual Report at 13.

The fugitive dust program conducted by Hecla Mining is only designed to measure emissions and not dispersion outside the foot print of the TDF and does not give sufficient data for use in standard dispersion models. Terrain, tree lines, particle size and other factors all complicate any estimation of dispersion.

Adding the total Pb loading collected in the south and southwest dust collectors since monitoring began in 2011 produces 1,317,972ug/m^2 (1.3 grams/m^2) of Pb that has been emitted in the general direction of the Greens Creek delta. Given that the Greens Creek delta is 41.3 hectares 413,000m^2) in area, if only ten percent (for the sake of analysis) of this Pb reaches and settles on the delta, then fugitive dust could have contributed approximately 53,700 grams (or about 120 pounds) of Pb to the delta in the 11 years monitoring has occurred.

From the data above, it is clear that fugitive dust from the TDF is being blown directly into Hawk Inlet or onto the Greens Creek delta and washed into Hawk Inlet with each tidal change. Winds during the high dust loading months generally are blowing away from Young Bay and combined with the distance, approximately 3 miles, fugitive dust is a minor, if any influence on Young Bay. Fugitive dust from the TDF facility must be considered a major anthropogenic source of Pb to the Greens Creek Delta and Hawk Inlet.

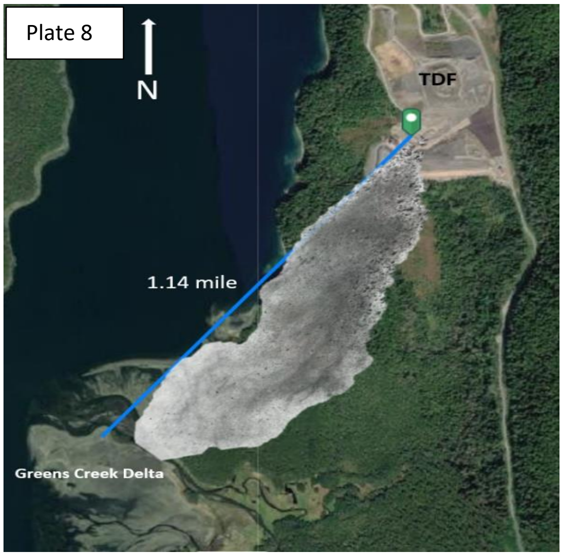


Plate 8: Rendition of possible dust plume (by Author).

8.0 *Conclusion*

For three decades, the observed increase of Pb in the marine environment of Hawk Inlet has been assumed to be due to natural occurrences, specifically erosion of the mineralized rock in the area. The original pre-production baseline studies cataloguing species diversity and populations and metal bioaccumulation in upper trophic organisms were designed to measure long-term effects of the mine on Hawk Inlet biota. Surprisingly, these baseline studies have never been repeated, so long-term effects of the mine's operation throughout the food chain in Admiralty Island National Monument remain unmeasured. The current monitoring program assumes indirectly that if tissue levels in bottom trophic level organisms and sediments remain under NOAA SQuiRT screening levels, then higher trophic levels are also protected. It also assumes that because Pb levels seem to be increasing at all monitoring stations, then it must be from a natural source even though one of the two sites (Site 3) used for comparison is known to be contaminated from human activity; possibly from fugitive dust.

Trends over long periods of time on metal concentrations such as Pb in the marine environment can be provided by the analysis of clamshells in regions experiencing isostatic uplift. This study shows that Pb in Hawk Inlet and in the natural area in Young Bay remained similar and consistent across centuries prior to mine activities, and only recently rose to the current observed levels. Levels of Pb in Hawk Inlet are now 45.7% higher than in Young Bay, an area underlaid by the same geology and undergoing the same rate of erosion.

The isotope ratios indicate the source of Pb in Hawk Inlet during the current production era is more closely related to the tailings than the source of Pb in the pre-production eras in both Hawk Inlet and Young Bay. Overall, the isotopes of Pb were similar in both Hawk Inlet and Young Bay, indicating the same natural mineralization occurs at both sites.

Given the geological similarities of both Hawk Inlet and Young Bay, natural erosion of mineralized rock cannot explain the recent 50% increase in Pb concentrations in Hawk Inlet versus Young Bay. An examination of other possible sources of Pb in Hawk Inlet fails to account for the increase. Furthermore, there is no reason to believe that natural erosion rates are higher now than they were in the past few centuries. Natural Pb contributions from erosion should show a consistent trend from the past to the present. However, this does not match any of the observations.

Given that the analysis and comparison of the stable isotopes of Pb indicate the Pb observed in contemporary living organisms is a closer match to the tailings from the mine than with organisms that lived prior to mine activities or outside of Hawk Inlet, and given that fugitive dust is cited as a source of contamination on the uplands, it is clear the increased Pb concentrations in Hawk Inlet are also anthropogenic in nature. Given all the available data, the most likely source is fugitive dust blowing from the tailing storage facility as predicted in the 2013 Record of Decision and Environmental Impact Study [35]. This conclusion aligns with the heuristic known as Occam's Razor; that one explanation is most likely more accurate than two explanations for the same observed phenomena.

This study would benefit from more data from identified raised beaches and samples of the tailings. Clearly, fugitive dust monitoring should extend out from the TDF and include the Greens Creek delta given the high probability that the delta acts to absorb and expose Hawk Inlet to Pb from the dust. The long-term effects on flora and fauna in both the marine and terrestrial environments could easily be measured by repeating the original baseline studies of species diversity and populations within the intertidal areas in Hawk Inlet, and analyzing metal loading in upper-level trophic terrestrial organisms. The identification of Admiralty Island as worthy of National Monument status compels land managers to protect this unique ecosystem, including the productivity and health of its connected marine environment.

9.0 *References and Notes*

[1] 2021 Hawk Inlet Monitoring Report at 21. Available at: https://dnr.alaska.gov/mlw/mining/large-mines/greens-creek/pdf/2021-Hawk-Inlet-Monitoring-Report.pdf

[2] Verbal communication between author and ADEC at Greens Creek Annual Meeting.

[3] Agency for Toxic Substances and Disease Registry, Environmental Health and Medicine Education. June, 2019. Available at: https://www.atsdr.cdc.gov/csem/leadtoxicity/what_lead.html

[4] Do Cd, Cu, Ni, Pb, and Zn biomagnify in aquatic ecosystems? Cardwell. Rick, et.al. 2013. Available at: https://pubmed.ncbi.nlm.nih.gov/23625131/#:~:text=Trophic%20transfer%20factors%2C%20calculatedfrom%20lab,occupying%20TL%203%20and%20higher.

[5] Carell B, Forberg S, Grundelius E, Henrikson, et.al. Can mussel shells reveal environmental history? International Journal of Fisheries and Aquaculture Vol. 1(2), pp. 014-021, July 2009. Available at https://hero.epa.gov/hero/index.cfm/reference/details/reference_id/82537.

[6] Huang, H & Wu, Jianyong & Wu, J. (2007). Heavy Metal Monitoring Using Bivalved Shellfish from Zhejiang Coastal Waters, East China Sea. Environmental monitoring and assessment. 129. 315-20.

[7] Deanna E. Conners, Westerfield S, Feyko A, et.al. Lead Accumulation in Soft Tissues and Shells of Asiatic Clams (Corbicula Fluminea). Proceedings of the 1999 Georgia Water Resources Conference held March 30-31, 1999, at the University of Georgia.

[8] J.R. Encinar, M. Moldovan, in Encyclopedia of Analytical Science (Second Edition), 2005. Available at: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/lead-isotope.

[9] Bindler R. Contaminated lead environments of man: reviewing the lead isotopic evidence in sediments, peat, and soils for the temporal and spatial patterns of atmospheric lead pollution in

Sweden. Environ Geochem Health. 2011.

[10] Cunha, B. C. A., et al. Pb Isotopic Signatures in Sediments of a Sub-Tropical Coastal Lagoon: Anthropogenic Sources for Metal Contamination in the Sepetiba Bay (SE — Brazil).” *Journal of Coastal Research*, Coastal Education & Research Foundation, Inc., 2009, pp. 797–801. Available at; http://www.jstor.org/stable/25737688.

[11] APDES Permit AK0043206 Final Fact Sheet. Available at: https://dnr.alaska.gov/mlw/mining/large-mines/greens-creek/pdf/gcapdesfactsheet_ak0043206.pdf. Last accessed 12/10/21.

[12] Hecla Greens Creek Mining Company’s 2017- 2021 Exploration Project Final Environmental Assessment Admiralty Island National Monument, Tongass National Forest, Juneau Alaska R10-MB-812a February 2017. Available at: https://www.fs.usda.gov/nfs/11558/www/nepa/104272_FSPLT3_3951155.pdf. Last accessed 12/13/21.

[13] Rudis, D., P. Schempf and M. Jacobson. 2001. Bald Eagle, Blue Mussel and Sediment Contamination Concentrations from Hawk Inlet. Poster Presentation. Juneau, AK.

[14] Holland, A.,M. Hiegel and W. Richkus 1981. Final Results of the 1981 Field program for the Greens Creek Project Part 1: Hawk Inlet and Young Bay and Part ii: Chatham Strait. Martin Marietta Corp Environmental Center Baltimore, MD.

[15] Linda H. Geiser, Derr, Christa, et.al. Air Quality Monitoring of the Tongass National Forest, Methods and Baseline using Lichens. September, 1997.

[16] M. Ridgway. Trace Metals and Organic Compounds in Seabed Sediments 1978-2016 Hawk Inlet & Young’s Bay, Admiralty Island, Alaska. Oceanus Alaska for Friends of Admiralty. 2016.

[17] M. Ridgway. Trace Metals in Edible Marine Species Hawk Inlet, Admiralty Island, Alaska. Oceanus Alaska for Friends of Admiralty. October 2015.

[18] Memo from Kyle Herbert: Hawk Inlet Intertidal Clam Investigation. Alaska Department of Fish and Game. December, 2016.

[19] Alaska Department of Environmental Conservation, Alaska Pollutant Discharge Elimination System Permit Fact Sheet Permit Number: AK0043206. Available at: https://dnr.alaska.gov/mlw/mining/large-mines/greens-creek/pdf/gcapdesfactsheet_ak0043206.pdf

[20] Hecla Hawk Inlet Monitoring Program 2021 Annual Report. March, 2022. Available at: https://dnr.alaska.gov/mlw/mining/large-mines/greens-creek/pdf/2021-Hawk-Inlet-Monitoring-Report.pdf.

[21] Total Maximum Daily Load for Metals in the Marine Sediments of Hawk Inlet near Juneau, Alaska. Alaska Department of Environmental Conservation. May 2017 (TMDL)

[22] Juneau Tide Station data available at: https://tidesandcurrents.noaa.gov/waterlevels.html?id=9452210.

[23] ALS Statement of Accreditation can be found at https://www.alsglobal.se/media-se/pdf/certificate-lulea-180918.pdf.

[24] Christopher F. Larsen, Roman J. Motyka, Jeffrey T. Freymueller, Keith A. Echelmeyer, Erik R. Ivins, Rapid uplift of southern Alaska caused by recent ice loss, *Geophysical Journal International*, Volume 158, Issue 3, September 2004, Pages 1118–1133. It was determined that Hawk Inlet area rate of isostatic rebound was 12.0mm/year. Sea level rise due to melting glaciers was 2.2mm/year. Age was determined from elevation above MLT in mm divided by 9.8mm/year.

[25] Hecla H1 2021 Biannual Report for the State of Alaska Waste Management Permit No. 2020DB0001. August, 2021. Available at: https://dnr.alaska.gov/mlw/mining/large-mines/greens-creek/pdf/2021-H1-Biannual-Report.pdf.

[26] P. Grandjean and T. Nielsen. Residue Res., 72 (1979) 97-148.

[27] Komarek, M., Ettler, V., Chrastný, V., Mihaljevic, M., 2008. Lead isotopes in environmental sciences: a review. Environ. Int. 34 (4), 562e577. http://dx.doi.org/10.1016/j.envint.2007.10.005.

[28] Cliff D. Taylor, Wayne R. Premo, and Craig A. Johnson. Sulfur and Lead Isotope Characteristics of the Greens Creek Polymetallic Massive Sulfide Deposit, Admiralty Island, Southeastern Alaska.

[29] 2020 H1 2020 Biannual Report and 2019 Fresh Water Monitoring Program Annual Report. Available at: https://dnr.alaska.gov/mlw/mining/large-mines/greens-creek/.

[30] Hecla Storm Water Monitoring Program 2021 Annual Report. March 2022. Available at: https://dnr.alaska.gov/mlw/mining/large-mines/greens-creek/pdf/2021-Storm-Water-Report.pdf

[31] Hecla H1 2020 Biannual Report for the State of Alaska Waste Management PermitNo. 2020DB0001. October 2020. Available at: https://dnr.alaska.gov/mlw/mining/large-mines/greens-creek/pdf/2020-HGCMC-H1-Biannual-Report-Final.pdf.

[32] Alaska Department of fish and Game. Aquatic Biomonitoring at Greens Creek Mine, 2020. Technical Report No. 21-06. March, 2021. Available at: https://dnr.alaska.gov/mlw/mining/large-mines/greens-creek/pdf/21-06-Aquatic-Biomonitoring-Greens-Creek-Mine-2020.pdf.

[33] Hecla Hawk Inlet Monitoring Program 2020 Annual Report. March, 2021. Available at: https://dnr.alaska.gov/mlw/mining/large-mines/greens-creek/pdf/2020-HGCMC-Hawk-Inlet-Monitoring-Report.pdf.

[34] Hecla H2 2020 Biannual Report, Hecla Greens Creek Mining Company. Available at: https://dnr.alaska.gov/mlw/mining/large-mines/greens-creek/pdf/2020-HGCMC-H2-Biannual-Report-Final.pdf.

[35] Greens Creek Mine Tailings Disposal Facility Expansion Record of Decision United States Department of Agriculture Forest Service R10-MB-744c. September 2013. Available at: https://dnr.alaska.gov/mlw/mining/large-mines/greens-creek/pdf/FEIS_ROD.pdf

[36] M. Izquierdo, A.M. Tye, S.R. Chenery, Sources, lability and solubility of Pb in alluvial soils of the River Trent catchment, U.K. Science of The Total Environment, Volume 433, 2012, Pages 110-122.

[37] Alaska Department of Environmental Conservation Waterbody Determination Paper Tributary Creek, Admiralty Island, Alaska Lead Determination, 2022. Available at: https://dec.alaska.gov/media/24730/2022-draft-tributary-creek-cat-4b-demonstration.pdf

Notes

M. Komarek, V. Ettler, V. Chrastny, and M. Mihaljevic, "Lead ´ isotopes in environmental sciences: a review," Environment International, vol. 34, no. 4, pp. 562–577, 2008

Mollusks are used in many studies as bio-indicators of environmental metallic concentrations because of their ability to accumulate and concentrate metals from seawater. The formation of calcareous shells during growth accumulates metals to a considerable extent. In the shell secretion mechanism, all the components for bio-mineralization come from the epithelial tissues of the mollusk and are secreted by the mantle during shell formation. Therefore, the trace elements present in the environment and assimilated by the animals are incorporated in the shells during their life. In particular, the shells store elements not needed by the organism, such as heavy metals (Bertine and Goldberg, 1972; Koide et al., 1982). Thus, the chemical composition of shells serves as a record of its environmental metal levels (Sturesson, 1976, 1978; Al-Dabbas et al., 1984; Bourgoin et al., 1991; Fuge et al., 1993) and moreover could also be used to compare present environmental metal levels with those of the past (Bourgoin and Risk, 1987; Carrel et al., 1987; Pitts and Wallace, 1994). When associated with metal concentrations, which indicate levels of pollution, Pb isotopic compositions are a powerful tool in tracing the origins of those metals.

Markich, S. J., Jeffree, R. A. & Burke, P. T. Environ. Sci. Technol. 36, 821–832 (2002). Freshwater bivalve shells as archival indicators of metal pollution from a copper-uranium mine supports the proposition that the shells of *V. angasi* can be used as archival indicators of metal pollution in surface water of the Finniss River over their lifetime.

Ravera, O., Cenci, R., Beone, G. M., Dantas, M. & Lodigiani, P. Trace Element concentrations in freshwater mussels and macrophytes as related to those in their environment. J. Limnol. 62, 61–70 (2003). Bioaccumulators can be regarded as a useful tool in long-term studies to follow pollutant variations in the same environment or when substantial differences in pollutant concentrations in different environments were found. This monitoring method yields reliable results to detect new pollutants contaminating the environment,

Heavy metals occur in aquatic environments from natural processes and anthropogenic activities (Connell et al., 1999; Franca et. al., 2005). The contamination of natural waters by heavy metals affects aquatic biota and poses considerable environmental risks and concerns (Cajaraville et al., 2000; Ravera, 2001; Otchere, 2003) and human health. Contaminants can persist for many years in sediments, where they hold the potential to affect human health and the environment (Mackeviiene et al., 2002). The analyses of water or sediment samples, however, are subject to a variety of shortcomings, in that the methods do not allow for the estimation of the quantity of the metal which is biologically available (Etim et al., 1991). It is against this background that bio-indicators are preferred in environmental monitoring. Bivalves are effective biomonitors and have been widely used for heavy metal monitoring *Corresponding author E-mail: steveamisah1@yahoo.co.uk purposes worldwide

Conners, D. Lead Accumulation in Soft Tissues And Shells Of Asiatic Clams (CORBICULA FLUMINEA) Deanna E. Conners, Stacy M. Westerfield, Anna Feyko and Marsha C. Black AUTHORS: Department of Environmental Health Science, Interdisciplinary Program in Environmental Toxicology, University of Georgia, 206 Environmental Health Science Building, Athens, Georgia 30602-2102. REFERENCE: Proceedings of the 1999 Georgia Water Resources Conference, held March 30-31, 1999, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, University of Georgia, Athens, Georgia.

Bivalves bioaccumulate metals and are useful as sentinel organisms for assessing the bioavailability of metal contaminants in aquatic ecosystems. Frequently, tissue metal concentrations are used by environmental monitoring studies to evaluate potential exposure and effects scenarios. However, bivalves may accumulate certain metals, such as lead, to a significant extent in shells.

Lead accumulation in clams exposed for three weeks increased with increasing Pb exposure concentrations was consistently higher in shells than soft tissues. (Figure · 1). Lead accumulation in shells was .... approximately 76 to 89% greater than accumulation in adductor muscle tissue and 48 to 700% greater than accumulation in ·foot tissue. Exposed clams show weak of depuration in Pb I shell. Most shells still contained elevated concentrations of Pb.

It has been proposed that bivalves accumulate Pb in the shell by two processes, an active process whereby Pb accumulated in soft tissues is transported to the mantle and deposited in the shell and a passive process whereby Pb from the surrounding environment physically adsorbs on to shell material (Sturensson, 1976). Once in the shell, the majority of Pb associates with the periostracum and calcium carbonate fractions (Sturensson, 1976). The use of shell Pb concentrations in environmental monitoring studies would be advantageous for many reasons. Sturensson (1978) notes that bivalve shells are easier to preserve than soft tissues and may also release metals at a slower rate during depuration periods. Hence, shell Pb concentrations would be useful for predicting environmental exposures from single point in time measurements. Findings from this study support this notion in that shell Pb concentrations in Asiatic clams remained stable during depuration.

HAWK INLET MONITORING PROGRAM
2022 ANNUAL REPORT

Hecla Greens Creek Mining Company

27 February 2023

CONTENTS

List of Charts

List of Tables

List of Figures

1. INTRODUCTION

1.1. Site Description

The Greens Creek Mine, located on Admiralty Island, is 18 miles southwest of Juneau, Alaska. Dense forests cover the mountain slopes up to an elevation of 2,500 feet, above which the vegetation is alpine. The climate is maritime, with precipitation averaging 60 to 70 inches per year at the mine site and 45 to 55 inches per year near the port facilities. The mine and mill facilities (920 area) are located over 6 miles from Hawk Inlet tidewater.

Zinc, lead, silver, and gold are the target recovery metals. The production of ore concentrate began in February 1989 and operated approximately four years before production was suspended in April 1993. The mine and mill were recommissioned, and operations restarted in mid-1996. A milling facility and support facilities are in place in the 920 area. Filter pressed tailings from the milling process are backfilled in the mine and deposited at a surface dry-stack tailings pile. Ore concentrate (concentrate) is transported from the mill to the Hawk Inlet port facilities area (Port) for storage until shipped. Support facilities for the mining and milling operation at the Port include rock core storage, concentrate storage, shift housing, and a domestic wastewater treatment plant.

One wastewater discharge outfall and ten stormwater discharge sites are authorized under the Alaska Pollutant Discharge Elimination System (APDES) Permit Number AK-0043206. This report fulfills the requirements of APDES Permit Number AK-0043206, effective 1 October 2015.

Hawk Inlet is a marine inlet formed during the late Holocene glaciation and is underlain by a series of late-Paleozoic to Mesozoic phyllitic-schist and greenstone formations. Hawk Inlet extends seven miles north from Chatham Strait to a tidal mudflat estuary about 0.6 miles in diameter. The narrow channel connecting the Inlet to Chatham Strait, located between the top of the Greens Creek delta and the western shore of Hawk Inlet, has a minimum low tide depth of 35 feet. The mid-channel depth ranges from 35 feet to 250 feet. Hawk Inlet has regular, twice-daily tides, with a maximum tidal variation of 25 feet. The surface 35-foot layer contains the bulk of the water transport entering the inlet on the flood tide, flushed out on the ebb tide. Flushing describes the rate and extent to which tidal or other currents replenish a body of water. Flushing rates indicate the length of time that mining effluent may remain in a water body and become incorporated into the physical and biological ecosystem through ingestion, adsorption, or other means. Dispersion dye testing in Hawk Inlet (the 1980s) determined that over each tidal cycle, an average of 13 billion gallons of water is flushed from the inlet (SEA 1983). At that rate, Hawk Inlet is estimated to flush once every five tidal cycles. Based on the average daily discharge rate, the effluent is approximately 0.007% of the total volume flushed daily.

Greens Creek geology exploration began in 1973, which led to the predevelopment of mining operations in 1986. Before this, the Hawk Inlet cannery was constructed in 1910 and operated until it burned in 1976. It is estimated that the summer population at Hawk Inlet during cannery operation was 500. Additionally, up until 1946, gold was mined near Hawk Inlet, beginning in 1919 at the Alaska Empire Mine (Forest Service 2013). “In September 2014, the Forest Service conducted a Preliminary Assessment/Site Inspection of the Alaska Empire Mine site. Elevated concentrations of metals were found in the soil, sediment, surface water, and groundwater at the Upper Camp and soil stained by petroleum hydrocarbons. Tailings piles with elevated concentrations remain adjacent to the creek and continue to erode tailings into the creek.” (Palmieri 2016).

1.2. Hawk Inlet Monitoring Program

In anticipation of the Greens Creek Mine development, government agencies, scientists, and biological consultants carried out surveys of marine life and baseline studies of heavy metals in the environment beginning in the early 1980s. The continual quarterly and annual monitoring programs have generated an extensive time-series data set of metal levels in the water, sediment, and marine tissue samples.

The Hawk Inlet monitoring program's primary objective is to document the water quality, sediment chemistry, and biological conditions in receiving waters and marine environments that the mine's operations may impact. Seawater is sampled quarterly at three locations in Hawk Inlet. Sediment and invertebrate samples are collected annually at three and seven spots, respectively (Figure 1-1). Additional sediment samples are collected at two locations every five years. Table 1-1 summarizes the requirements of the permit for sample parameters, sample preservation and holding time, sampling frequency, analytical method, and required method detection limits (MDL). Specific quality assurance/quality control (QA/QC) requirements (i.e., sampling procedures, documentation, chain of custody processes, calibration procedures and frequency, data validation, corrective actions, etc.) are outlined in the APDES Quality Assurance Project Plan: Project Monitoring Manual (HGCMC 2020).

This report presents information on each of the media sampled in Hawk Inlet: water column, sediment, and in-situ bioassay. Results for the samples collected are presented along with the associated QA/QC data. Statistical evaluation of the data showing averages, variations, and changes over time are included. The next section describes any deviations from the monitoring program that occurred and the reasons why.

1.3. Deviation(s) from Monitoring Program and Incidents

Samples were not analyzed for TSS at Site 108 and WAD Cyanide at Site 107 during the 2nd Quarter sampling event. There was a mistake during sample collection where the incorrect bottles were used so the samples were not properly preserved for these two analytes.

1.4. Outfall 002 Pipeline and Diffuser Inspection

Along with the annual environmental monitoring, the Outfall 002 pipeline is inspected annually. On October 17, 2022, Global Diving & Salvage, Inc., surveyed the pipeline and diffuser for corrosion and damage. The report and video from the survey are in Appendix B. The following recommendations summarize the notable findings of the inspection:

- The overall condition of the pipeline and diffuser is very good.
- Anode depletion should be monitored annually.
    - Based on previous inspection intervals and estimated anode depletion, the expected functional status of anodes could be 2-3 years.

Table 1-1 Summary of Permit Sampling Requirements for Hawk Inlet

APDES Requirement	Parameter	Frequency	Type	Sample Container	Sample Preservation	Laboratory	Hold Times	Analytical Method(s)	Minimum Required Method Detection Limit	Units
RECEIVING WATER COLUMN MONITORING										
1.6.1.1.3 Table 5	Dissolved Cadmium	Quarterly	Grab	1 ea. 500 ml Teflon bottle (1 bottle for Cd, Cu, Pb, Zn)	HNO_3 to pH <2 by lab	Battelle Marine Sciences	180 day	EPA 213.2/ 1638	0.10	µg/L
1.6.1.1.3 Table 5	Dissolved Copper							EPA 220.2/ 1638	0.03	µg/L
1.6.1.1.3 Table 5	Dissolved Lead							EPA 239.2/ 1638	0.05	µg/L
1.6.1.1.3 Table 5	Dissolved Zinc							EPA 289.2/ 1638	0.200	µg/L
1.6.1.1.3 Table 5	Total Mercury			1 ea. 250 ml Teflon bottle			28 day	EPA 245.1/ 1631	0.002	µg/L
1.6.1.1.3 Table 5	Total Suspended Solids			1 ea. 500 ml plastic bottle	Cool to 4°C	ACZ Labs	7 day	EPA 160.2/ SM 2540D	--	mg/L
1.6.1.1.3 Table 5	WAD Cyanide			1 ea. 500 ml plastic bottle	NaOH to pH >12, cool to 4°C		14 day	EPA 335.2/ SM 4500-CN-E	5.00	µg/L
1.6.1.1.3 Table 5	Turbidity			1 ea. 125 ml plastic bottle	Cool to 4°C	Field Measurement	2 day	EPA 180.1	--	NTU
1.6.1.1.3 Table 5	pH			NA	NA		15 min	EPA 150.1/ SM 4500-H, B	--	SU
1.6.1.1.3 Table 5	Conductivity			NA	NA		20	EPA 120.1	--	µmhos/cm
1.6.1.1.3 Table 5	Temperature			NA	NA		15 min	NA	--	°C
BIOACCUMULATION WATER SEDIMENT MONITORING										
1.6.1.2.3 Table 6	Total Cadmium	Annual	Grab	6 ea. 8 oz. plastic or glass jar	Chill and ice sample (not frozen)	ALS		PSEP/GFAA	0.30	mg/Kg
1.6.1.2.3 Table 6	Total Copper							PSEP/ICP	15.00	mg/Kg
1.6.1.2.3 Table 6	Total Lead							PSEP/ICP	0.50	mg/Kg
1.6.1.2.3 Table 6	Total Mercury							PSEP/ EPA 7471A	0.02	mg/Kg
1.6.1.2.3 Table 6	Total Zinc							PSEP/ICP	15.00	mg/Kg
BIOACCUMULATION WATER IN-SITU BIOASSAY MONITORING										
1.6.1.3.2 Table 7	Total Cadmium	Annual	Grab	6 ea. 8 oz. plastic or glass jar	Chill and ice sample (not frozen)	ALS		EPA 200.8/ 6020	not specified	mg/Kg
1.6.1.3.2 Table 7	Total Copper							EPA 200.8/ 6020	not specified	mg/Kg
1.6.1.3.2 Table 7	Total Lead							EPA 200.8/ 6020	not specified	mg/Kg
1.6.1.3.2 Table 7	Total Mercury							EPA 7471A	not specified	mg/Kg
1.6.1.3.2 Table 7	Total Zinc							EPA 200.8/ 6020	not specified	mg/Kg

2. WATER COLUMN MONITORING

The receiving water column monitoring requirements originate from Part 1.6.1.1 and Table 5 of the APDES permit. The receiving water column monitoring element of the sampling program aims to provide scientifically valid data on specific physical and chemical parameters for Hawk Inlet water quality. These data are used to evaluate potential changes in the Hawk Inlet marine environment.

Seawater samples are collected quarterly from the sites on an outgoing tide, with the Chatham Strait sample (Site 106) collected just after low, slack water. The two other sites are Station 107, located about mid-way east-west in Hawk Inlet, west of the ship loader facility, and Station 108, located proximal to the Outfall 002 diffuser at the edge of the mixing zone. Samples at these locations are taken at a depth of five feet. The sample timing in each quarter is tide and weather dependent. As required by Permit Part 1.6.3.2, quarterly receiving water sample collection occurs on the same day as effluent sample collection.

Water samples are sent to Battelle Marine Science Laboratory in Sequim, Washington, for low-level mercury and dissolved trace metals analyses (Cd, Cu, Pb, and Zn) and ACZ Laboratories in Steamboat Springs, Colorado for WAD CN and total suspended solids analyses. Temperature, pH, turbidity, and conductivity are measured in the field by HGCMC personnel.

2.1. Analytical Results

The tables in this section summarize the results for the quarterly water column monitoring.

Table 2-1 Hawk Inlet Field Parameters

Quarter	Sample date	Site Number	Sample Time	Water Temperature (°C)	pH (s.u.)	Conductivity (µmhos/cm @ 25°C)	Turbidity (NTU)
1	2022-03-08	106	10:30	3.7	7.8	51,400	1.0
		107	10:00	3.6	7.7	50,700	1.2
		108	10:20	3.6	7.7	50,600	1.1
2	2022-05-31	106	08:40	7.9	8.0	51,300	0.8
		107	09:30	9.1	8.3	48,300	0.7
		108	09:11	9.4	8.4	45,080	0.7
3	2022-08-02	106	11:10	13.5	8.3	36,140	0.6
		107	10:25	13.0	8.1	42,420	0.6
		108	10:45	12.6	8.3	43,270	0.7
4	2022-12-12	106	09:35	4.7	7.8	49,600	1.2
		107	10:25	3.9	7.8	49,600	1.2
		108	10:05	3.8	7.8	48,200	1.1

Table 2-2 Hawk Inlet Water Column Monitoring

Sample Quarter	Site	TSS (mg/L)	WAD CN (µg/L)	Cd (µg/L) Dissolved	Cu (µg/L) Dissolved	Hg (µg/L) Total	Pb (µg/L) Dissolved	Zn (µg/L) Dissolved
	Lab MDL	*(5.0)*	*(3.0)*	*(0.002)*	*(0.023)*	*(0.0001)*	*(0.005)*	*(0.042)*
	Req. MDL		*(5.0)*	*(0.10)*	*(0.03)*	*(0.002)*	*(0.05)*	*(0.20)*
1	106	20.00	<3	0.08	0.25	0.0003	<0.005	0.37
	107	21.00	<3	0.08	0.25	0.0005	0.01	0.48
	108	27.00	<3	0.08	0.24	0.0003	<0.005	0.50
2	106	46.00	5.30	0.07	0.20	0.0002	<0.005	0.09
	107	47.00	--	0.07	0.25	0.0003	<0.005	0.36
	108	--	7.30	0.06	0.28	0.0026	0.02	0.44
3	106	14.00	<3	0.04	0.38	0.0002	<0.005	0.21
	107	18.00	<3	0.05	0.38	0.0006	0.01	0.47
	108	21.00	<3	0.05	0.42	0.0005	0.01	1.27
4	106	31.00	<3	0.09	0.29	0.0002	0.01	0.35
	107	37.00	<3	0.10	0.38	0.0003	0.01	0.48
	108	36.00	<3	0.10	0.34	0.0003	0.01	0.90

Note

1. A '--' denotes the sample was not collected

2.2. Data Evaluation

Figures 2-1a, b, c through 2-7a, b, c show the time series plots of field pH, conductivity, cadmium, copper, lead, mercury, and zinc for stations 106 (2-1a through 2-7a), 107 (2-1b through 2-7b) and 108 (2-1c through 2-7c). The Alaska Water Quality Standards (AWQS) for marine aquatic life – chronic levels are shown or noted on the relevant graphs. The graphs show that Hawk Inlet water quality has remained within AWQS standards for all samples.

Figures 2-8a through 2-8f are the comparative time series plots of field pH, cadmium, copper, lead, mercury, and zinc from the last 10 years for station 108 and Outfall 002. The graphs demonstrate that the mixing zone authorized by the APDES permit is protective of the AWQS for all measured parameters.

Table 2-3 compares monitoring results averaged from the previous five years (n=20) and last year's (n=4) results at the three seawater monitoring locations. The results for the reporting period remained near the last five-year average.

Table 2-3 Hawk Inlet Water Column Average Dissolved Metal Concentrations

Site	Cd (µg/L)		Cu (µg/L)		Pb (µg/L)		Hg (Total - µg/L)		Zn (µg/L)	
	2017 through 2021	**2022**	**2017 through 2021**	**2022**	**2017 through 2021**	**2022**	**2017 through 2021**	**2022**	**2017 through 2021**	**2022**
106	0.072	0.069	0.24	0.28	0.008	0.01	0.0002	0.0002	0.42	0.26
107	0.075	0.073	0.28	0.32	0.010	0.01	0.0006	0.0004	0.44	0.45
108	0.075	0.073	0.42	0.32	0.014	0.01	0.0004	0.0009	0.63	0.78

2.3. Laboratory QA/QC Results

Battelle Marine Sciences Laboratory and ACZ Laboratories analyzed the required parameters (refer to Table 1-1) in the seawater samples. Complete QA plans and reports are kept on file in each laboratory's office and are available upon request. This section summarizes the relevant laboratory QA/QC results from each laboratory for the quarterly seawater samples. Elevated zinc levels in the field blanks, often at levels higher than all the other seawater samples, have been noted consistently by Battelle for this sampling program.

<u>Battelle Marine Science (low level dissolved trace metals analyses in saltwater matrices):</u>

1Q: The analytes of interest were found at detectable levels in all field samples with the exception of Pb at site 106-5 and 108-5, which were below the MDL. Concentrations in the method blank were less than the MDL for all metals. Concentrations in the field blank were less than the MDL for all metals with the exception of Cu, Zn and Pb, which were detected at 1.92, 2.85 and 1.30 times the MDL, respectively. No corrective action was taken considering this is less than 10 times the MDL. Trip blank results were below the MDL for all metals with the exception of Cu and Zn, which were detected at 1.77 and 1.02 times the MDL. No corrective action was taken considering this is less than 10 times the MDL. Target detection limits (TDLs) were met for all metals. Standard reference material (SRM), matrix spike and duplicate results were within our default criteria of 77-123%, 71-125%, and ±25%, respectively.

2Q: The analytes of interest were found at detectable levels in all field samples with the exception of Pb at sites 106-5 and 107-5, which were below the MDL. Concentrations in the method blank were less than the MDL for all metals. Concentrations in the field blank were less than the MDL for all metals with the exception of Pb and Zn, which were detected at 1.08 and 2.46 times the MDL, respectively. No corrective action was taken considering this is less than the reporting limit (i.e., 4 times the MDL). Trip blank results were below the MDL for all metals with the exception of Cu, which was detected at 1.28 times the MDL. No corrective action was taken considering this is less than the reporting limit. Target detection limits (TDLs) were met for all metals. Standard reference material (SRM), matrix spike and duplicate results were within our default criteria.

3Q: The analytes of interest were found at detectable levels in all field samples with the exception of Pb at site 106-5, which was below the MDL. Concentrations in the method blank were less than the MDL for all metals. Concentrations in the field blank were less than the MDL for all metals with the exception of Cu, Pb, and Zn, which were detected at 2.56, 4.04, and 48.0 times the MDL, respectively. This is not a concern for Cu and Pb since this is below the reporting limit (i.e., 4 times the MDL). The high levels of Zn in the field blank are potentially due to an issue that was previously identified when not enough water is passed through the filter prior to sample collection to rinse any residual cleaning acid. A larger bottle of DI will be sent for the next sampling. These results are not concerning for field samples considering large amounts of sample is rinsed through the filters prior to field sample collection. Trip blank results were below the MDL for all metals with the exception of Cu and Zn, which were detected at 1.28 and 8.61 times the MDL, respectively. This is not a concern for Cu since this is below the reporting limit. The elevated Zn levels in the trip blank were substantially lower than in the field blank, but may indicate a slight source of contamination at some point in the sampling or sample handling process. We will review laboratory sample handling procedures conducted to ensure contamination doesn't arise from lab handling. Target detection limits (TDLs) were met for all metals. Standard reference material (SRM), matrix spike and duplicate results were within our default criteria.

4Q: The analytes of interest were found at detectable levels in all field samples. Concentrations in the method blank were less than the MDL for all metals. Concentrations in the field blank were less than the MDL for all metals with the exception of Cu and Zn, which were detected at 1.61 and 4.61 times the MDL, respectively. No corrective action was taken considering this is less than the reporting limit (i.e., 4 times the MDL) for Cu and field samples had concentrations greater than 10 times the MDL with the exception of site 106-5. Trip blank results were below the MDL for all metals with the exception of Cu, which was detected at 1.11 times the MDL. No corrective action was taken considering this is less than the reporting limit. Target detection limits (TDLs) were met for all metals. Standard reference material (SRM), matrix spike and duplicate results were within our default criteria.

ACZ Laboratories (WAD cyanide analyses):

1Q: No certification qualifiers associated with this analysis.

2Q: No certification qualifiers associated with this analysis.

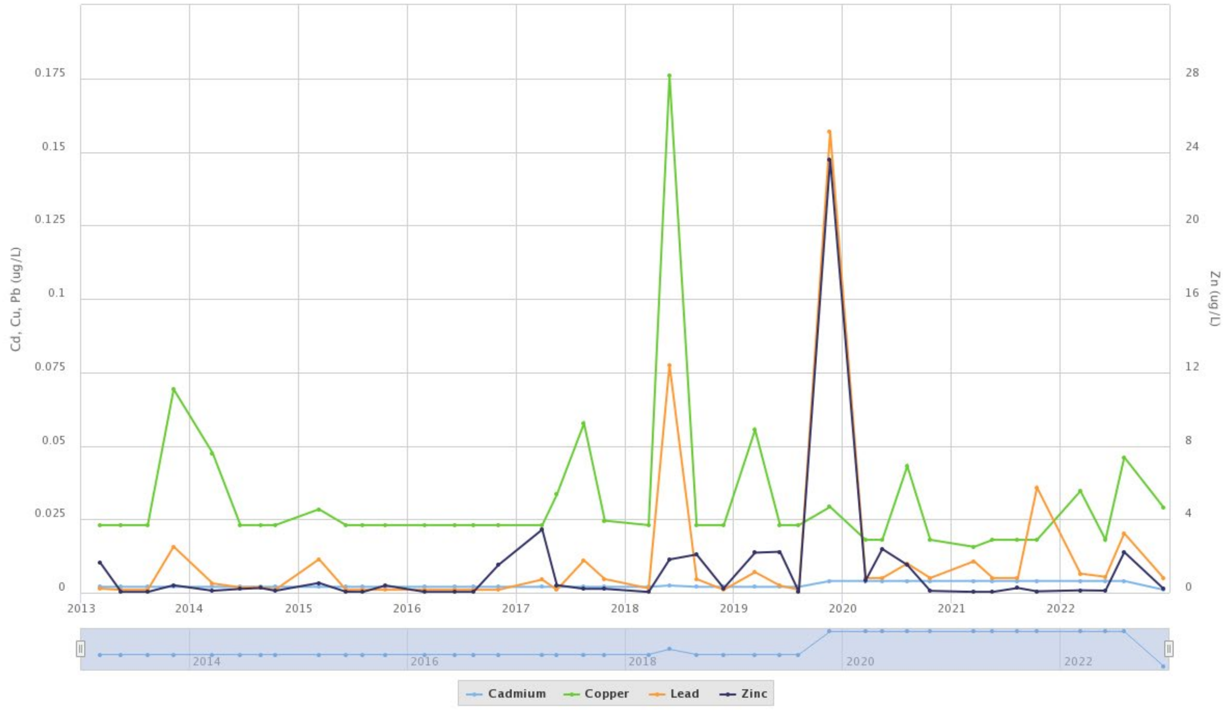
3Q: No certification qualifiers associated with this analysis.

4Q: No certification qualifiers associated with this analysis.

2.4. Field Blank Zinc Detection

As mentioned in section 2.3 and other Hawk Inlet monitoring reports, zinc is routinely detected in the field blank sample but not the actual seawater samples. HGCMC has always taken steps to minimize the potential contamination of the seawater and blank samples. Before 2009, Battelle provided water for the field blank locally sourced from the Pacific Ocean near Sequim, Washington, after which they began to provide deionized water. This switch is evident with the field blank data set (Chart 2-1).

Chart 2-1 2006-2022 Quarterly Field Blank Dissolved Metal Results



The average field blank value for dissolved zinc over the last 10 years is greater than the results for Site 106, Site 107, and Site 108. If HGCMC sampling procedures systematically introduce a contaminant into the field blank sample, the seawater samples should be similarly tainted. However, this is not the case.

All sampling supplies are provided by BML. Bottles and pump tubes are reused after acid-washing. The filter capsules are new but acid-washed. The bottles and tubes are not maintained to a specific sample. If they were the source of contamination, the errant zinc values would be randomly distributed. BML supplies the same deionized water for the field blank and trip blank samples, and rarely are metals detected in the trip blank. Removing these pathways leaves minimal possibilities for contaminating the field blank.

HGCMC speculates that the contamination is entering the sample from the filter capsule. The acid-washed filter capsules are necessary for the sub-microgram detection limits. However, the field blank filter capsules have not been as thoroughly rinsed as the actual seawater sample filter capsules. For years BML provided 1L of water for rinsing the filter, pump tubing, and sample bottle and then collecting a 0.5L and 0.25L sample. Recently, they have been sending 2L of water for rinsing and collection. Increasing the rinse volume on the filter to nearly 1L, whereas before, it was around 0.2L. Also, HGCMC has implemented controls to ensure that all filter capsules have an equal volume of seawater or DI water flushed through them before the sample is collected.

3. SEDIMENT MONITORING

The sediment monitoring requirements originate from Section 1.6.1.2, Sediment Monitoring, and Table 6 of the APDES permit. This monitoring program element aims to provide scientifically valid data on five specific trace metal parameters analyzed as the dry weight (dw) from sediments at four Hawk Inlet locations (see Figure 1-1 for locations). These data are used to evaluate potential changes in the Hawk Inlet marine environment over time.

Sediment samples were collected semi-annually through 2015. With the re-issuance of the permit, the sampling frequency was changed to annual. Samples are collected at the Greens Creek delta (Site S-1), Pile Driver Cove near the mouth of the inlet (Site S-2), ~400 feet south of the concentrate loading facility (Site S-4), and under the loading facility at Sites S-5N and S-5S. Sites S-5N and S-5S were established in response to the 1989 concentrate spill. These two sites are sampled every five years per permit condition 1.6.1.2. Sampling sites S-1, S-2, and S-3 were chosen to represent natural conditions. The results from these sites from September 1984 until January 1989 were used to calculate baseline values.

Station S-3 near the head of Hawk Inlet, established initially as a background site, has been sampled for sediment and biota since the 1980s. Though dropped from the official sampling program with the permit reissuance in 2005, HGCMC continued to monitor the site yearly and has included the data in this report.

3.1. Sediment Analytical Results

Marine Taxonomic Services, LTD collected all sediment samples. The sample locations, dates, times, weather conditions, and tides are shown in Table 3-1. Table 3-2 summarizes the total metals results for the sediment monitoring events. Sample replicates (reps) 1 through 6 were averaged for each sample site.

Samples are analyzed at ALS Environmental in Kelso, Washington, for total concentrations of cadmium, copper, lead, mercury, and zinc.

Table 3-1 Hawk Inlet Sediment Monitoring Field Parameters

Location	Date Sampled	Time Sampled (24 hour)	Air Temperature (°F)	Weather Conditions	Tide (ft MLLW)
S-1	10/11/2022	2045	47	Light rain, overcast	-1.3
S-2	10/10/2022	2000	46	Light rain, mostly cloudy	-1.3
S-3	10/8/2022	0628	50	Light rain and fog	-0.7
S-4	10/8/2022	0731	50	Light rain and fog	0.0

3.2. Data Evaluation

Before opening the Greens Creek Mine for full production in 1989, 5 locations were chosen for sediment sampling for heavy metal concentrations. This data is valuable to compare metal values after mining began and the current year's sampling results. Sampling sites S-4 and S-5N, and S-5S are located near the ore concentrate loading facility. They are thought to have been influenced by the old industrial cannery operation and not representative of natural conditions. However, these sites were used to establish a pre-operational baseline condition.

Figures 3-1 through 3-5 show the time series plots for cadmium, copper, lead, mercury, and zinc, including replicate samples for sample site S-1. Figures 3-6 through 3-10 show the time series plots for cadmium, copper, lead, mercury, and zinc, including replicate samples for sample site S-2. . Figures 3-11 through 3-15 show the metal time-series graphs for site S-4. Replicate samples are plotted with a single point, representing the mean value of the data and error bars to represent the distribution. In 2004, replicate sampling began, and all replicate samples were included, plotted by the mean with standard error bars unless otherwise noted.

Table 3-2 shows the average metal concentrations and the associated standard deviations for each sediment sampling site during pre-production, production, and the current year. At site S-1, located at the Greens Creek delta and closest to Outfall 002, average concentrations of heavy metals were less than or similar to the average production and pre-production period concentrations.

At site S-2, the background site in Pile Driver Cove located approximately three miles south of the port facilities, the average concentrations during the reporting period were higher than the production and pre-production period averages.

Site S-3 is located near Hawk Inlet's head and approximately four miles north of the Greens Creek Mine port facilities. The average concentrations for all metals during the reporting period were greater than the pre-production and production averages at this location. Furthermore, the average metals concentrations were higher than those at the other sediment monitoring locations. Given these data and the spatial distance between the monitoring locations, it is evident that all metal inputs to Hawk Inlet are not associated with the Greens Creek Mine.

Average concentrations of heavy metals at S-4 were less than or similar to the average production period and pre-production period averages.

Table 3-2 Sediment Data Comparison of Pre-Production, Production, and Current Year Values

Station	Period	Cd (mg/kg)		Cu (mg/kg)		Pb (mg/kg)		Hg (mg/kg)		Zn (mg/kg)	
		Avg	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*
S-1	**Pre-Production (9/1984 - 2/1989) (n=9)**	0.22	0.11	21.78	3.8	7.79	2.1	0.043	0.01	125.01	7.7
	Production (2/1989 - 12/2021) (n=142)	0.18	0.18	16.18	6.9	7.23	3.8	0.030	0.03	100.80	30.7
	Reporting Year 2022 (n=6)	0.12	0.01	15.15	0.8	6.29	0.2	0.020	0.00	114.00	5.0
S-2	**Pre-Production (9/1984 - 2/1989) (n=9)**	0.27	0.11	14.90	2.6	5.27	2.4	0.028	0.01	60.47	5.4
	Production (2/1989 - 12/2021) (n=142)	0.14	0.11	10.46	4.4	2.23	1.5	0.010	0.02	43.64	12.7
	Reporting Year 2022 (n=6)	0.41	0.10	31.28	8.7	6.07	1.7	0.040	0.01	74.25	14.2
S-3	**Pre-Production (9/1984 - 2/1989) (n=9)**	0.62	0.28	37.00	9.1	10.03	3.3	0.067	0.02	127.03	49.8
	Production (2/1989 - 12/2021) (n=142)	0.79	0.33	38.39	10.9	14.90	4.4	0.070	0.03	139.59	35.8
	Reporting Year 2022 (n=6)	1.26	0.31	61.30	6.9	22.77	3.6	0.110	0.01	207.67	27.9
S-4	**Pre-Production (9/1984 - 2/1989) (n=6)**	0.34	0.17	46.23	12.1	53.78	20.2	0.109	0.06	136.53	41.6
	Production (2/1989 - 12/2021) (n=142)	0.49	0.80	31.71	45.1	53.37	118.3	0.100	0.45	103.42	155.6
	Reporting Year 2022 (n=6)	0.40	0.06	33.50	22.5	24.48	8.7	0.050	0.03	79.27	9.4

Note:

1. Non-detects are averaged using half of the MDL

3.3. QA/QC Results

ALS Environmental analyzed the required parameters (see Table 1-1) in the sediment samples. Complete QA plans and reports are kept on file at the ALS Environmental office and are available upon request. The remainder of this section summarizes any relevant QA/QC results that were exceptions during the reporting period.

Replicate samples have been collected from each site, when possible, to address a National Marine Fisheries Service request since 2004. Replicate precision is evaluated using the Relative Standard Deviation (RSD).

RSD = (standard deviation * 100) / sample mean

The RSDs for the 2022 replicate samples are in Table 3-3.

The data quality objective for the RSD is that it is less than or equal to 30 percent when the values are at least four times the detection limit. All data met this criteria except for Site S-4 copper and lead results. High RSD values are the result of having one outlier replicate result.

Table 3-3 Relative Standard Deviation for Replicate Sediment Samples

Site	Rep	Sample Date	Cd (mg/kg dw)	Cu (mg/kg dw)	Pb (mg/kg dw)	Hg (mg/kg dw)	Zn (mg/kg dw)
S-1 Sediments	1	10/11/2022	0.13	14.40	6.11	<0.02	113.00
	2		0.11	15.30	6.40	0.02	112.00
	3		0.12	15.00	6.26	0.02	110.00
	4		0.14	16.50	6.67	0.02	125.00
	5		0.11	14.10	6.08	0.02	113.00
	6		0.11	15.60	6.21	0.03	111.00
		RSD (%)	***10.1***	***5.7***	***3.5***	--	***4.8***
S-2 Sediments	1	10/10/2022	0.41	21.00	3.95	<0.027	60.40
	2		0.35	30.50	5.86	0.04	71.10
	3		0.38	29.10	5.67	0.04	68.20
	4		0.32	26.90	5.26	0.04	68.90
	5		0.41	31.00	6.20	0.04	71.90
	6		0.62	49.20	9.50	0.06	105.00
		RSD (%)	***25.7***	***30.4***	***30.5***	--	***21.0***
S-3 Sediments	1	10/8/2022	1.24	59.60	22.20	0.10	206.00
	2		1.57	70.60	25.70	0.13	244.00
	3		0.95	53.30	19.00	0.12	178.00
	4		0.86	52.50	18.30	0.10	170.00
	5		1.24	63.70	22.90	0.11	208.00
	6		1.72	68.10	28.50	0.10	240.00
		RSD (%)	***26.5***	***12.3***	***17.1***	***10.9***	***14.7***
S-4 Sediments	1	10/8/2022	0.34	16.50	13.20	0.02	62.10
	2		0.40	22.60	20.30	0.07	82.50
	3		0.52	24.80	24.40	0.09	94.30
	4		0.39	83.10	42.10	0.03	78.40
	5		0.39	23.70	23.10	0.03	78.60
	6		0.38	30.30	23.80	0.04	79.70
		RSD (%)	***15.5***	***73.7***	***39.1***	--	***13.0***

4. IN-SITU BIOASSAYS

The bioassay monitoring requirements originate from Section 1.6.1.3, In-situ Bioassays, and Table 7 of the APDES permit. This monitoring element's objective is to provide scientifically valid data on five specific trace metal parameters analyzed at dry weight from the tissues of polychaete worms (*Nephtys*) and blue mussels (*Mytilus edulis*) at seven locations in Hawk Inlet for evaluating potential changes in the Hawk Inlet marine environment.

Bioaccumulation in-situ bioassay sampling in Hawk Inlet consists of annual testing of trace metal tissue burdens of selected species of invertebrate organisms with different feeding guilds. In the Hawk Inlet sill area, where no fine-grained sediments occur, monitoring trace metals in blue mussels occur at four sites (Stations STN-1, STN-2, STN-3, and East Shoal Light (ESL)). Data gathered from this area measures organisms' response near the Outfall 002 discharge. In most other regions of Hawk Inlet, the bottom is covered with sediment. Consequently, samples of sediment-dwelling polychaete worms (*Nephtys procera and Nereis sp.*) are collected at three additional sites (S-1, S-2, and S-4). *Nereis sp*. were not encountered in sufficient numbers for analysis during the reporting period, so only *Nephtys* were collected.

4.1. Analytical Results

Marine Taxonomic Services, LTD collected all tissue samples (Table 4-1).

Table 4-1 Hawk Inlet Tissue Sampling Field Data

Location	Sample Type	Date Sampled	Time Sampled (24 hour)	Air Temperature (°F)	Weather Conditions	Tide (ft MLLW)
S-1	Nephtys	10/11/2022	2045	47	Light rain, overcast	-1.3
S-2	Nephtys	10/10/2022	2000	46	Light rain, mostly cloudy	-1.3
S-3	Nephtys	10/8/2022	0628	50	Light rain and fog	-0.7
S-4	Nephtys	10/8/2022	0731	50	Light rain and fog	0.0
STN-1	Mussels	10/8/2022	1715	50	Light rain, mostly cloudy	3.4
STN-2	Mussels	10/10/2022	1748	46	Light rain, mostly cloudy	5.8
STN-3	Mussels	10/9/2022	1800	51	Light rain, mostly cloudy	3.2
ESL	Mussels	10/10/2022	1815	46	Light rain, mostly cloudy	3.6

4.2. Data Evaluation

Biota tissues were sampled for heavy metal concentrations before opening the Greens Creek Mine for full production in 1989. Results for mussels from sites STN-1, STN-2, STN-3, and ESL, and *Nephtys* from sites S-1, S-2, and S-3 from September of 1984 until January of 1989 were used to calculate baseline, pre-production values. These data are helpful as baseline values against which to compare metal values after mining began and the current year's sampling results.

As noted by the Oceanographic Institute of Oregon in the 1998 Kennecott Greens Creek Mine Risk Assessment (p 4-3),

> *"Sampling stations were selected to demonstrate a range of potential exposures including "worst case" exposure to Outfall discharges. Some of the test organisms placed in cages directly on the Outfall diffuser ports lived for six months. These results indicate that even maximum exposure to the Outfall discharge results in no acute effects."*

The average and standard deviation results for pre-production, production, and current year periods for mussels are provided in Table 4-2. In the reporting period, cadmium, copper, mercury and zinc concentrations were lower than or similar to the pre-production period. Lead concentrations were greater than the pre-production period for all sites.

Table 4-2 Average and Standard Deviation Values for Pre-Production, Production, and Current Year Mussel Data

Station	Period	**Cd** (mg/kg)		**Cu** (mg/kg)		**Pb** (mg/kg)		**Hg** (mg/kg)		**Zn** (mg/kg)	
		Avg	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*
ESL	**Pre-Production (9/1984- 2/1989) (n=9)**	6.67	1.60	8.16	0.68	0.42	0.11	0.03	0.01	91.40	8.38
	Production (2/1989- 12/2021) (n=92)	6.80	1.12	9.86	2.83	1.03	0.28	0.03	0.02	85.40	13.97
	Reporting Year 2022 (n=6)	4.83	0.06	6.11	0.12	0.68	0.02	0.04	0.01	66.05	0.88
STN-1	**Pre-Production (9/1984 - 12/1989) (n=9)**	7.41	1.80	7.96	1.20	0.62	0.41	0.07	0.09	94.92	11.21
	Production (2/1989- 12/2021) (n=92)	9.29	1.54	7.91	2.25	1.18	0.75	0.04	0.02	95.31	21.47
	Reporting Year 2022 (n=6)	7.63	0.08	5.79	0.08	0.67	0.01	0.04	0.01	85.78	0.93
STN-2	**Pre-Production (9/1984 - 12/1989) (n=9)**	8.60	3.10	7.71	1.05	0.37	0.19	0.04	0.01	82.36	11.20
	Production (2/1989- 12/2021) (n=92)	9.36	1.60	8.23	2.76	1.19	0.55	0.04	0.02	92.91	23.78
	Reporting Year 2022 (n=6)	8.08	0.11	6.05	0.11	0.56	0.29	0.04	0.00	84.83	1.02
STN-3	**Pre-Production (9/1984 - 12/1989) (n=9)**	9.27	3.05	8.50	1.69	0.59	0.21	0.04	0.01	95.73	17.80
	Production (2/1989- 12/2021) (n=92)	9.45	1.51	7.76	1.78	1.16	0.62	0.04	0.02	93.89	10.69
	Reporting Year 2022 (n=6)	5.48	0.15	7.68	0.13	0.77	0.05	0.04	0.01	82.53	1.33

Note:

1. Non-detects are averaged using half of the MRL/MDL.

The metal concentrations in *Nephtys* are shown in Table 4-3. Concentrations of cadmium and mercury in *Nephtys* show a general decline over time. Mercury concentrations were similar to or lower at all four sample stations relative to pre-production and production levels. Zinc concentrations were comparable to the pre-production and production levels. Cadmium concentrations were comparable to the pre-production and production levels. Copper concentrations were similar to or lower than pre-production. Lead concentrations at S-1 have been higher on average since production began relative to pre-production. Lead concentrations at the other stations were lower in the reporting period than the production and pre-production average concentrations. Figures 4-21 through 4-35 show the time series plots for cadmium, copper, lead, mercury, and zinc, including replicate samples in *Nephtys* for sample sites S-1, S-2, and S-4. Replicate samples are plotted by the mean and include standard error bars. Samples from site S-3 are being collected, although not required by the permit. This data is included to provide additional background information.

Table 4-3 Average and Standard Deviation Values for Pre-Production, Production, and Current Year Nephtys Data

Station	Period	Cd (mg/kg)		Cu (mg/kg)		Pb (mg/kg)		Hg (mg/kg)		Zn (mg/kg)	
		Avg	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*	*Avg*	*Stdev*
S-1	**Pre-Production (9/1984- 2/1989) (n=9)**	4.00	1.61	9.04	1.12	0.49	0.15	0.05	0.01	243.6	40.1
	Production (2/1989- 12/2021) (n=140)	2.92	0.79	10.23	3.04	1.00	0.68	0.04	0.02	213.2	22.5
	Reporting Year 2022 (n=6)	1.72	0.04	9.18	0.49	1.44	0.05	0.04	0.01	185.7	1.7
S-2	**Pre-Production (9/1984- 2/1989) (n=9)**	1.70	0.70	12.37	3.12	0.59	0.22	0.02	0.01	181.1	27.7
	Production (2/1989- 12/2021) (n=140)	1.09	0.18	8.75	2.04	0.69	0.20	0.02	0.01	172.8	20.7
	Reporting Year 2022 (n=6)	2.00	0.03	8.86	0.65	0.47	0.02	0.02	0.00	197.2	2.3
S-3	**Pre-Production (9/1984- 2/1989) (n=8)**	4.08	2.45	16.45	4.92	0.82	0.45	0.14	0.22	241.4	70.7
	Production (2/1989- 12/2021) (n=138)	1.99	0.51	14.12	5.90	0.88	0.50	0.04	0.02	237.0	25.2
	Reporting Year 2022 (n=6)	1.47	0.01	9.99	0.37	0.68	0.06	0.05	0.00	244.0	2.3
S-4	**Pre-Production (9/1984- 2/1989) (n=2)**	1.21	0.70	16.80	6.70	4.16	1.27	0.11	0.06	193.5	10.5
	Production (2/1989- 12/2021) (n=140)	0.78	0.26	17.92	10.19	6.55	1.17	0.02	0.01	193.2	22.4
	Reporting Year 2022 (n=6)	0.46	0.01	5.24	0.11	2.73	0.09	0.02	0.00	169.5	2.0

Note:

1. Non-detects are averaged using half of the MRL/MDL.

4.3. QA/QC Results

ALS Environmental analyzed the required parameters (see Table 1-1) for the bioassay samples. Complete QA plans and reports are kept on file at the ALS Environmental office and are available upon request. This section summarizes the relevant QA/QC results for the sampling completed during the reporting period.

No anomalies associated with the analysis of these samples were observed.

Since the fall of 2004, replicate samples have been collected from each site, where possible, to address a National Marine Fisheries Service request. Precision can be calculated from the results of replicative samples. In this case, RSD is shown for the replicate samples in Table 4-4. The data quality objective for the RSD is that it is less than or equal to 30% when the values are at least four times the detection limit. All RSDs calculated for the duplicate samples were within this data quality objective, except for lead in mussels at STN-2.

Table 4-4 Relative Standard Deviation for Replicate Tissue Samples

Sample ID	Rep	Date	Cd (mg/kg dw)	Cu (mg/kg dw)	Pb (mg/kg dw)	Hg (mg/kg dw)	Zn (mg/kg dw)
S-1 Nephtys	1	10/11/2022	1.76	10.20	1.54	0.04	186.00
	2		1.75	9.21	1.38	0.04	187.00
	3		1.72	9.19	1.45	0.04	184.00
	4		1.65	8.67	1.42	0.05	183.00
	5		1.73	8.89	1.43	0.03	188.00
	6		1.71	8.96	1.42	0.04	186.00
		RSD (%)	***2.3***	***5.8***	***3.8***	--	***1.0***
S-2 Nephtys	1	10/10/2022	1.97	8.41	0.45	<0.02	196.00
	2		2.04	8.72	0.47	<0.019	201.00
	3		2.03	8.54	0.47	<0.02	196.00
	4		1.98	10.30	0.51	0.02	199.00
	5		1.98	8.69	0.46	0.02	194.00
	6		1.97	8.50	0.46	0.03	197.00
		RSD (%)	***1.6***	***8.1***	***4.3***	--	***1.3***
S-3 Nephtys	1	10/8/2022	1.48	9.79	0.63	0.05	245.00
	2		1.48	9.90	0.64	0.04	243.00
	3		1.47	10.80	0.70	0.04	245.00
	4		1.46	9.74	0.79	0.05	241.00
	5		1.46	9.77	0.64	0.05	242.00
	6		1.49	9.95	0.69	0.05	248.00
		RSD (%)	***0.82***	***4.0***	***8.98***	--	***1.0***
S-4 Nephtys	1	10/8/2022	0.46	5.31	2.65	<0.02	170.00
	2		0.44	5.30	2.80	0.03	170.00
	3		0.47	5.29	2.77	0.02	171.00
	4		0.47	5.29	2.71	<0.019	172.00
	5		0.44	5.00	2.61	<0.019	166.00
	6		0.45	5.24	2.86	<0.019	168.00
		RSD (%)	***2.83***	***2.3***	***3.45***	--	***1.3***
ESL Mussels	1	10/10/2022	4.81	6.11	0.68	0.02	66.80
	2		4.82	6.20	0.70	0.04	66.20
	3		4.83	6.07	0.64	0.04	65.50
	4		4.95	6.30	0.65	0.04	67.40
	5		4.77	6.04	0.69	0.03	65.70
	6		4.81	5.93	0.70	0.04	64.70
		RSD (%)	***1.3***	***2.1***	***3.8***	--	***1.5***
STN-1 Mussels	1	10/8/2022	7.60	5.89	0.68	0.06	86.70
	2		7.68	5.85	0.69	0.04	86.70
	3		7.63	5.80	0.64	0.05	86.10
	4		7.45	5.80	0.65	0.06	85.20
	5		7.64	5.68	0.66	0.05	84.70
	6		7.57	5.84	0.65	0.04	85.00
		RSD (%)	***1.1***	***1.2***	***2.8***	--	***1.0***
STN-2 Mussels	1	10/10/2022	7.98	5.87	0.40	0.04	82.90
	2		8.13	6.09	1.20	0.04	85.20
	3		8.25	6.22	0.43	0.05	86.30
	4		8.05	6.02	0.42	0.04	84.50
	5		7.93	6.02	0.47	0.04	84.90
	6		8.13	6.09	0.41	0.04	85.20
		RSD (%)	***1.44***	***1.9***	***57.08***	--	***1.3***
STN-3 Mussels	1	10/9/2022	7.64	5.62	0.85	<0.02	81.80
	2		7.75	5.42	0.73	0.02	83.20
	3		7.55	5.43	0.70	0.04	81.70
	4		7.80	5.52	0.82	0.04	83.50
	5		7.83	5.68	0.75	0.07	84.50
	6		7.49	5.21	0.79	0.04	80.50
		RSD (%)	***1.81***	***3.1***	***7.2***	--	***1.8***

Notes:

1. A '--' indicates RSD was not calculated because three or more of the values was less than 4 times the MRL.
2. A '<' denotes the sample was analyzed for but was not detected above the MRL/MDL.

5. REFERENCES

Alaska Department of Environmental Conservation (ADEC). (2015). *Alaska Pollutant Discharge Elimination System (APDES) Permit AK-0043206*.

Oregon Institute of Oceanography, and Remediation Technologies, Inc. (1998). *Kennecott Greens Creek Mine Risk Assessment NPDES Permit No. AK-004320-6.*

Palmieri, Anne. (2016). *Site Report: USFS Empire Mine*. http://dec.alaska.gov/Applications/SPAR/PublicMVC/CSP/SiteReport/4198

Slotta Engineering Associates, Inc. (SEA). (1983). *1983 Environmental Studies Greens Creek Mining Joint Venture: Hawk Inlet.*

USDA Forest Service (2013). *Greens Creek Mine Tailings Disposal Facility Expansion: Final Environmental Impact Statement and Record of Decision*.

6. FIGURES

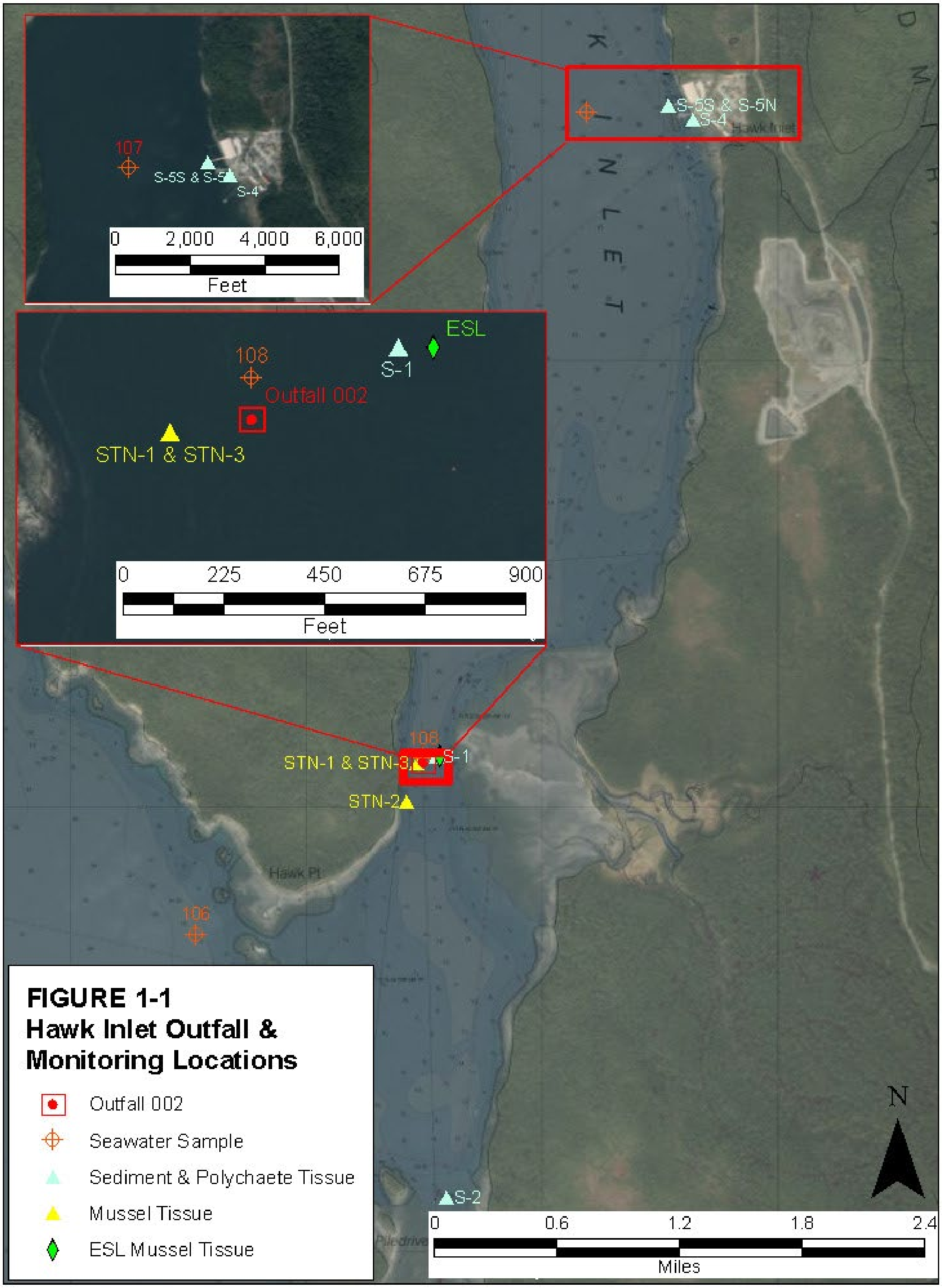


FIGURE 1-1
Hawk Inlet Outfall & Monitoring Locations

Figure 2-1a. Site 106 - Field pH

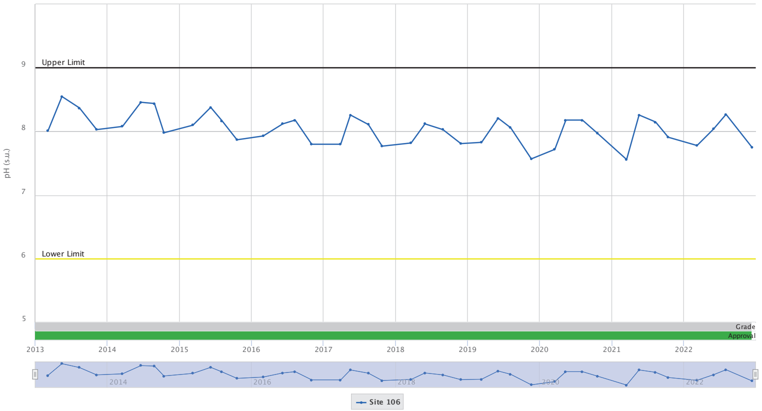


Figure 2-1b. Site 107 - Field pH

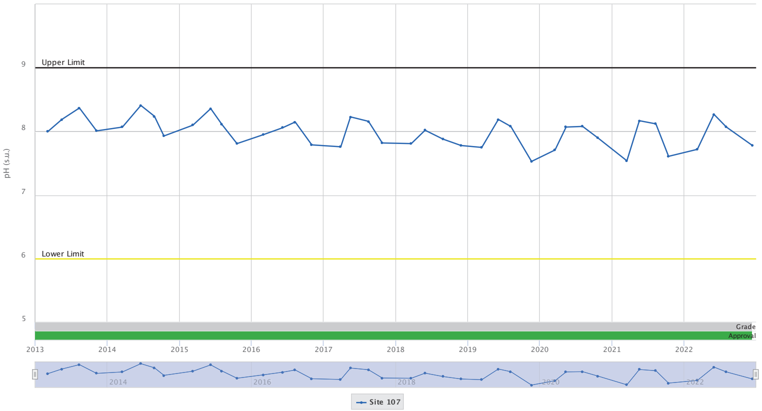


Figure 2-1c. Site 108 - Field pH

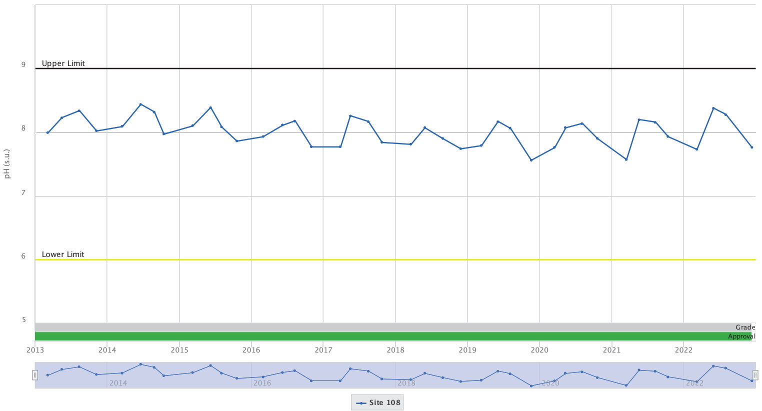


Figure 2-2a. Site 106 - Field Conductivity

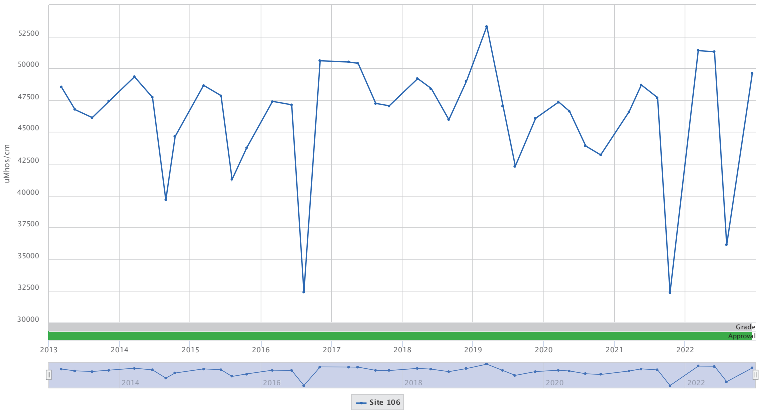


Figure 2-2b. Site 107 - Field Conductivity

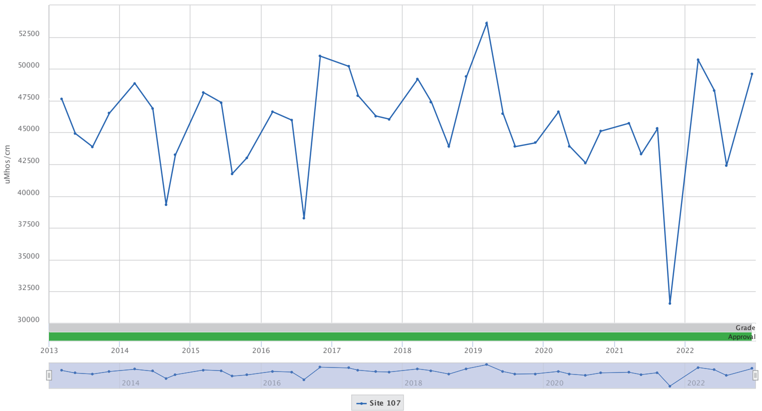


Figure 2-2ca. iSe t 10 - Fie6 doCl ucSniSv

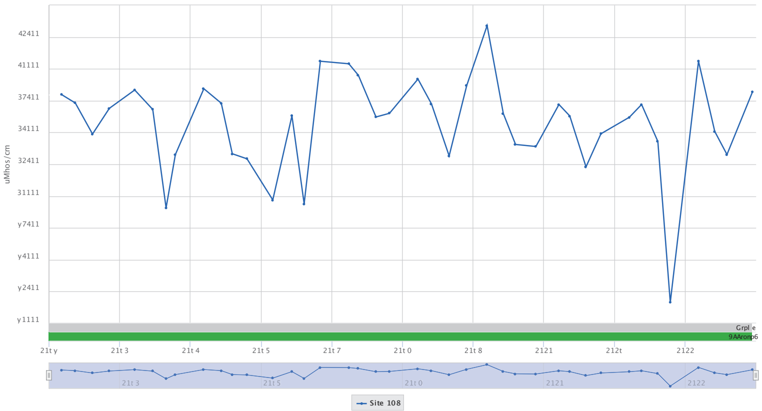


Figure 2-3a. Site 106 – Cadmium

Saltwater AWQS: 8.8 ug/L

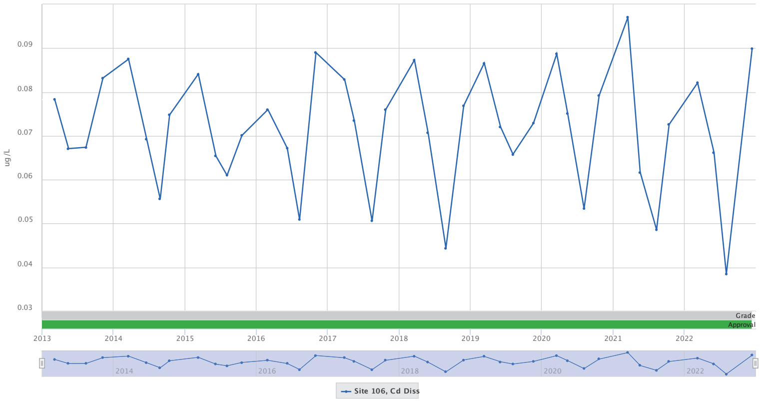


Figure 2-3b. Site 107 – Cadmium

Saltwater AWQS: 8.8 ug/L

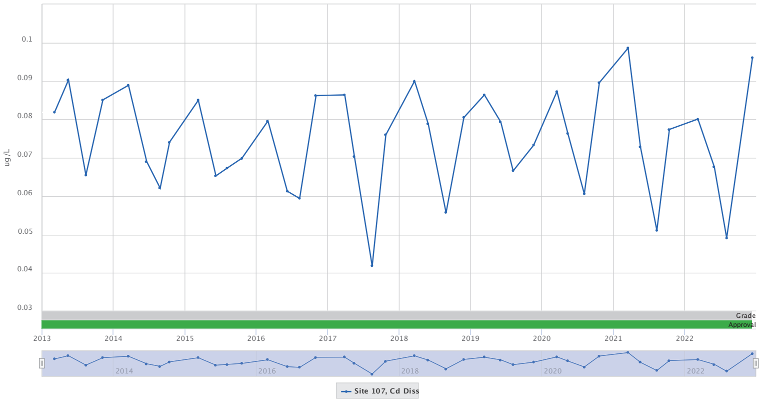


Figure 2-3c. Site 108 – Cadmium

Saltwater AWQS: 8.8 ug/L

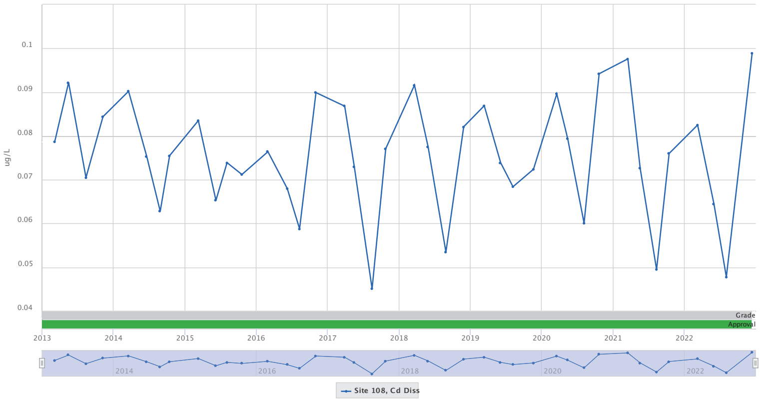


Figure 2-4a. Site 106 – Copper

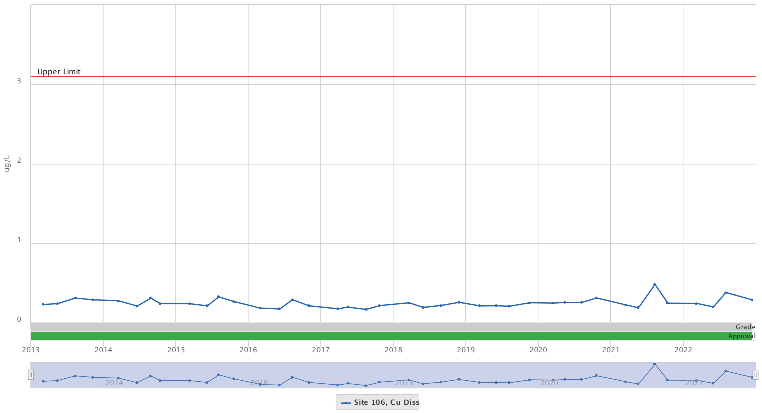


Figure 2-4b. Site 107 – Copper

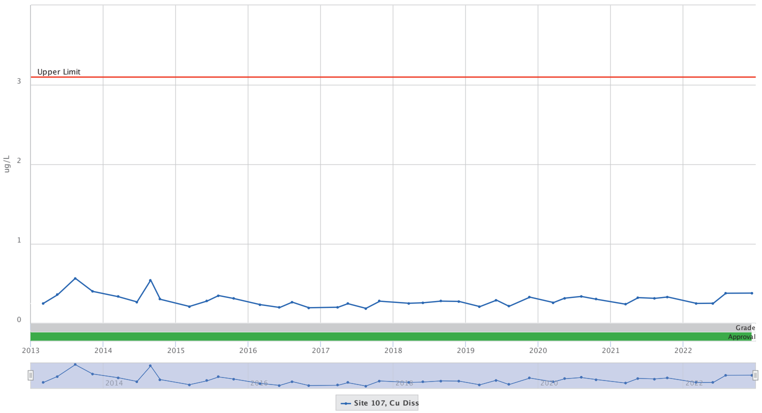


Figure 2-4c. Site 108 – Copper

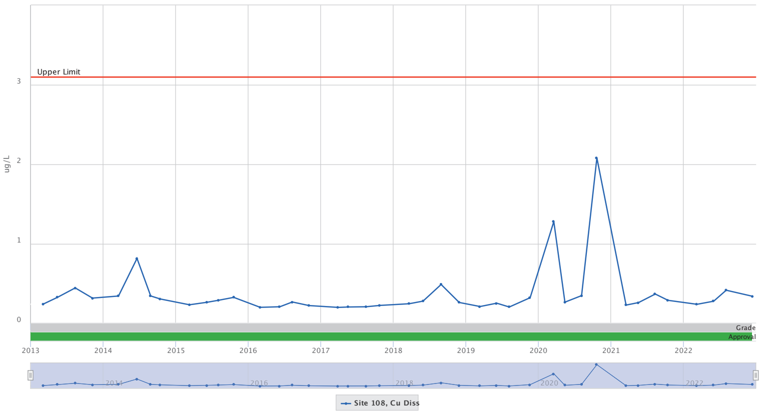


Figure 2-5a. Site 106 - Mercury

Saltwater AWQS: 0.94 ug/L

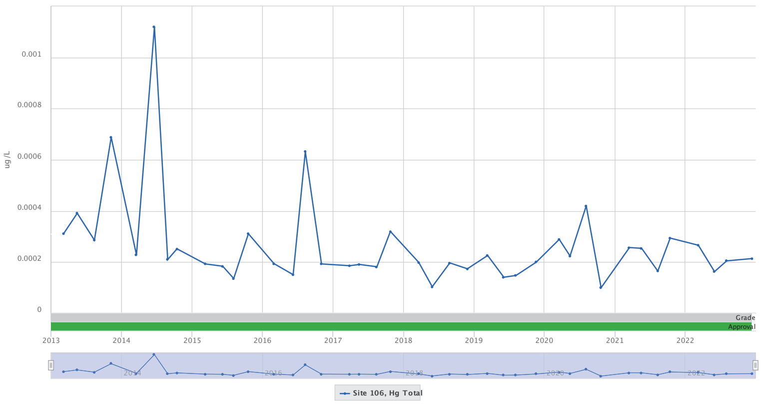


Figure 2-5b. Site 107 - Mercury

Saltwater AWQS: 0.94 ug/L

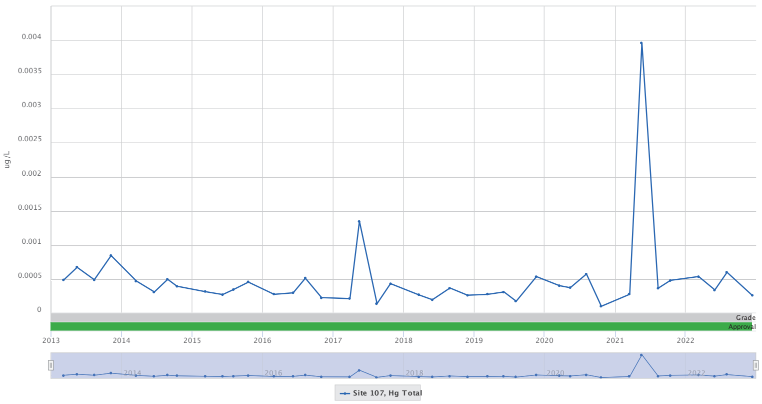


Figure 2-5a. Site 106 - Meraurc

Syltwyter AWQS: 0.94 ug/L

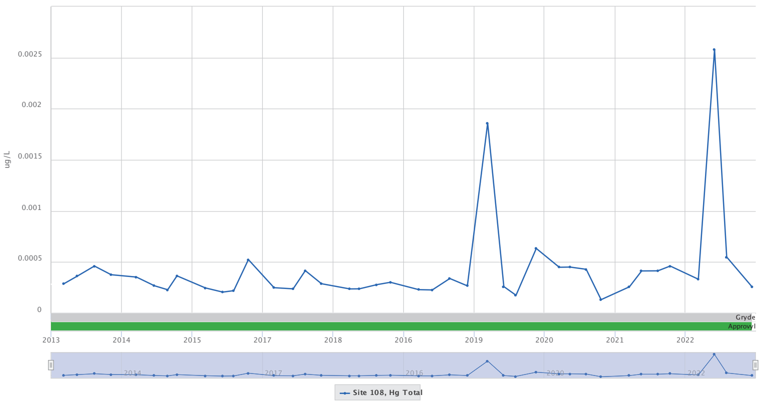


Figure 2-6a. Site 106 - Lead

Saltwater AWQS: 8.05 ug/L

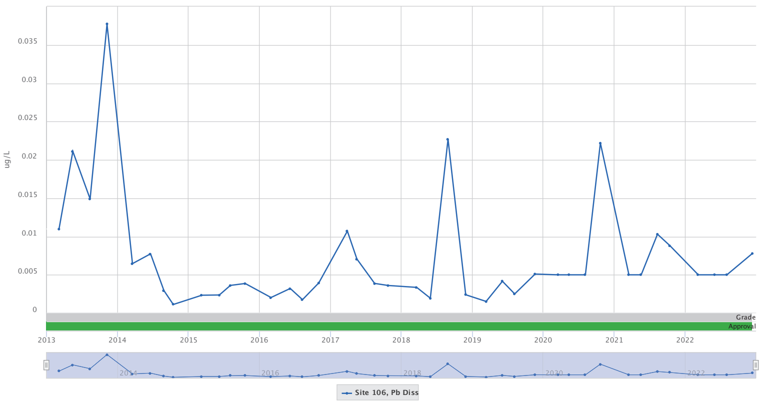


Figure 2-6b. Site 107 - Lead

Saltwater AWQS: 8.05 ug/L

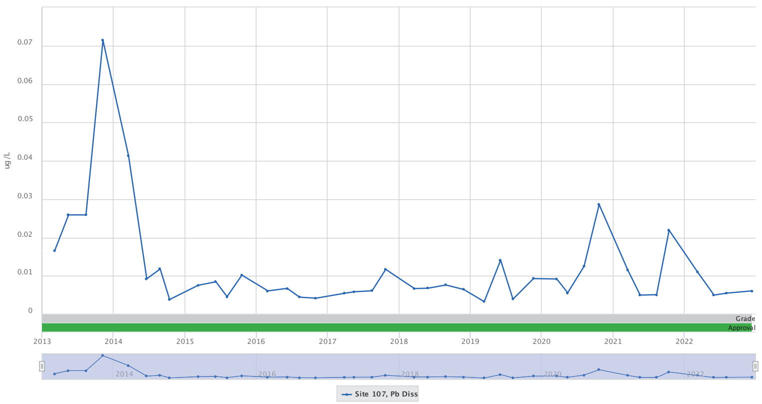


Figure 2-7b. Site 107 - Zn

Saltwater AWQS: 81.5 ug/L

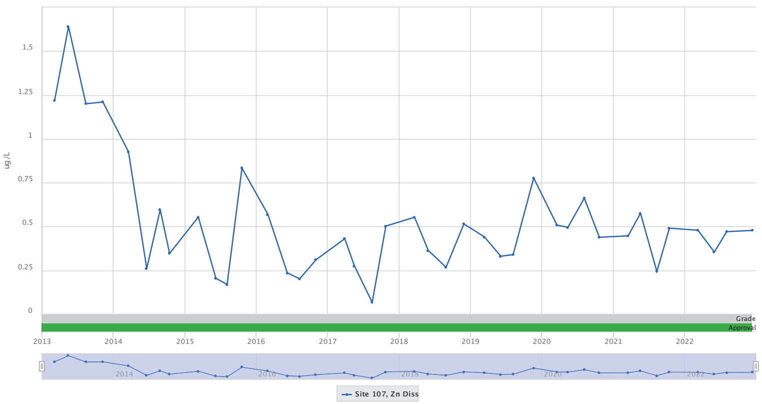


Figure 2-7a. Site 106 - Zn

Saltwater AWQS: 81.5 ug/L

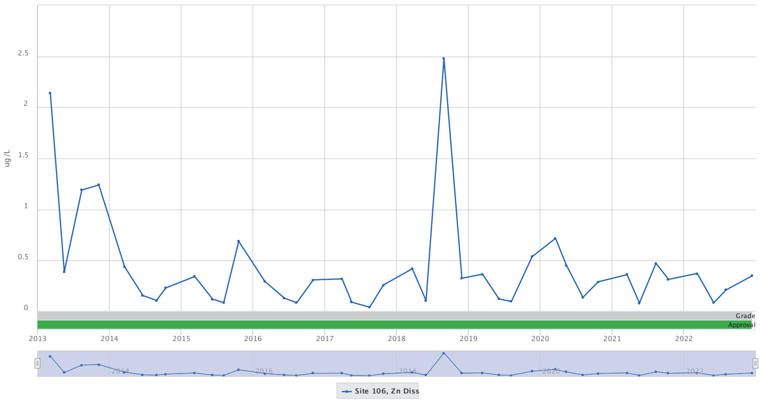


Figure 2-6c. Site 108 - Lead

Saltwater AWQS: 8.05 ug/L

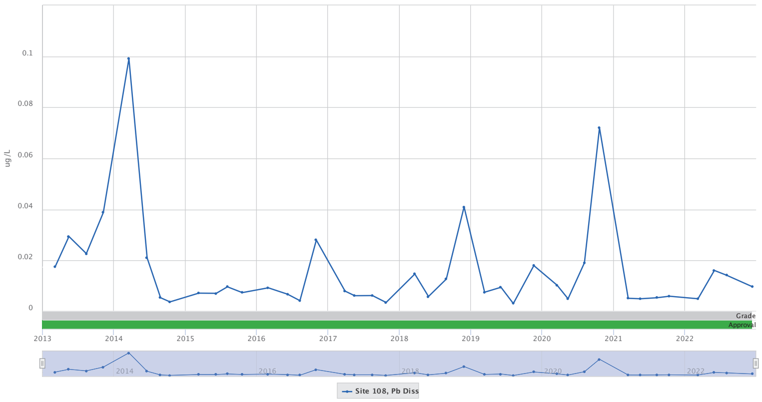


Figure 2-7c. Site 108 - Zn

Saltwater AWQS: 81.5 ug/L

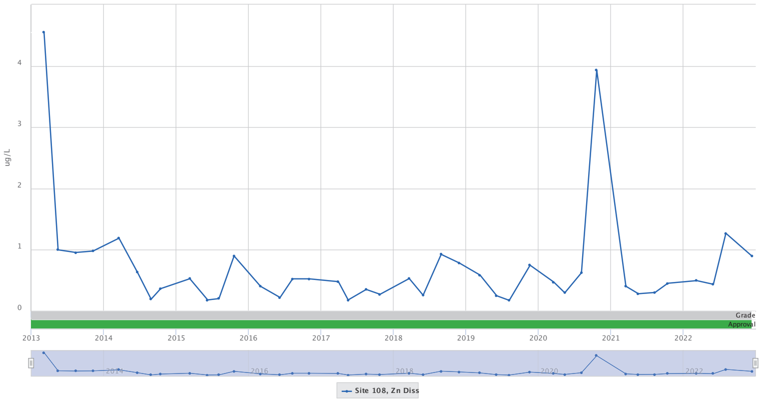


Figure 2-8a. Site 108 and Outfall 002 – Cadmium

Outfall 002 Daily Max Limit: 50 ug/L – Saltwater AWQS: 8.8 ug/L

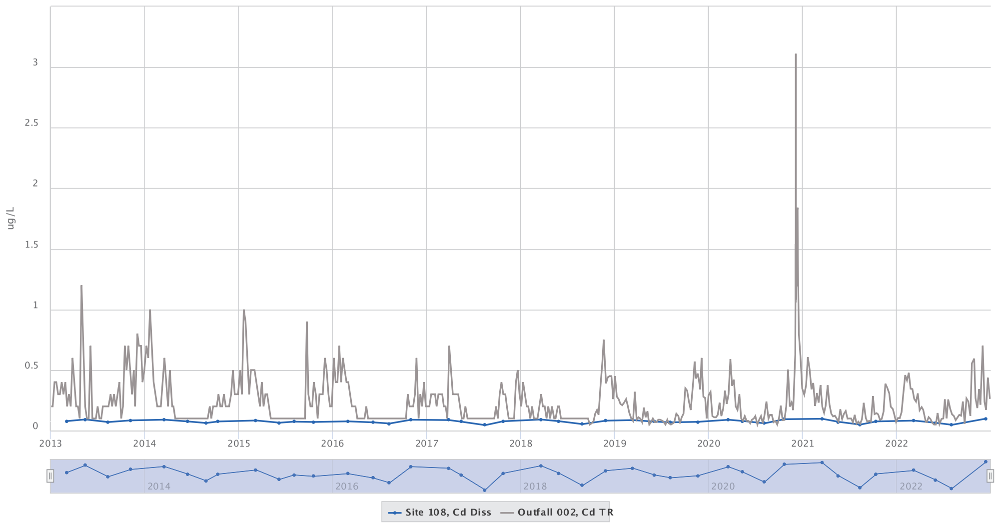


Figure 2-8b. Site 108 and Outfall 002 – Copper

Outfall 002 Daily Max Limit: 99 ug/L – Saltwater AWQS: 3.1 ug/L

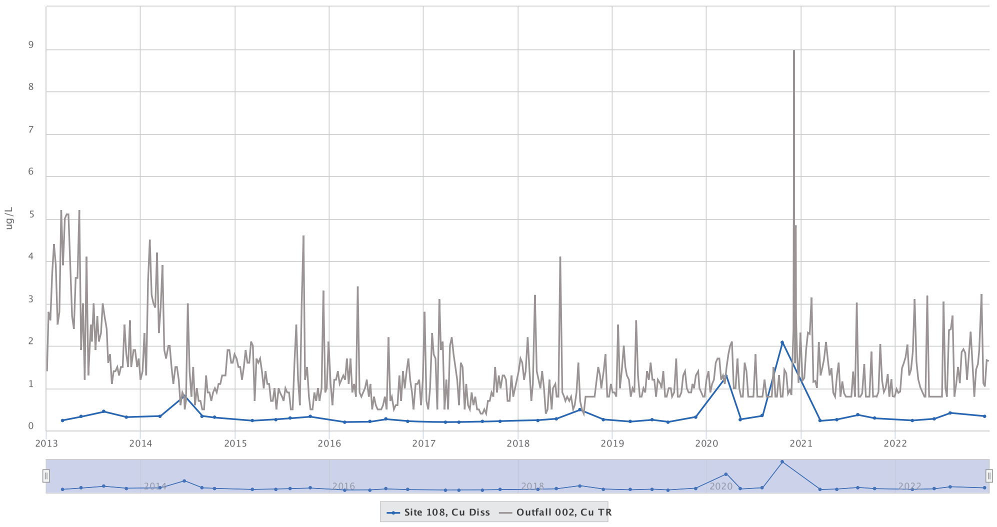


Figure 2-8c. Site 108 and Outfall 002 – Mercury

Outfall 002 Daily Max Limit: 1.9 ug/L – Saltwater AWQS: 0.94 ug/L

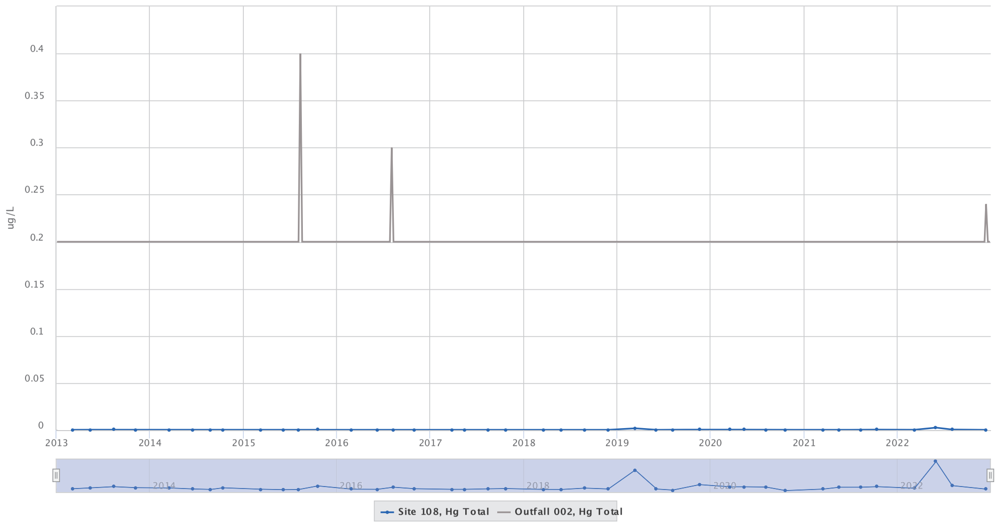


Figure 2-8d. Site 108 and Outfall 002 – Lead

Outfall 002 Daily Max Limit: 327 ug/L – Saltwater AWQS: 8.05 ug/L

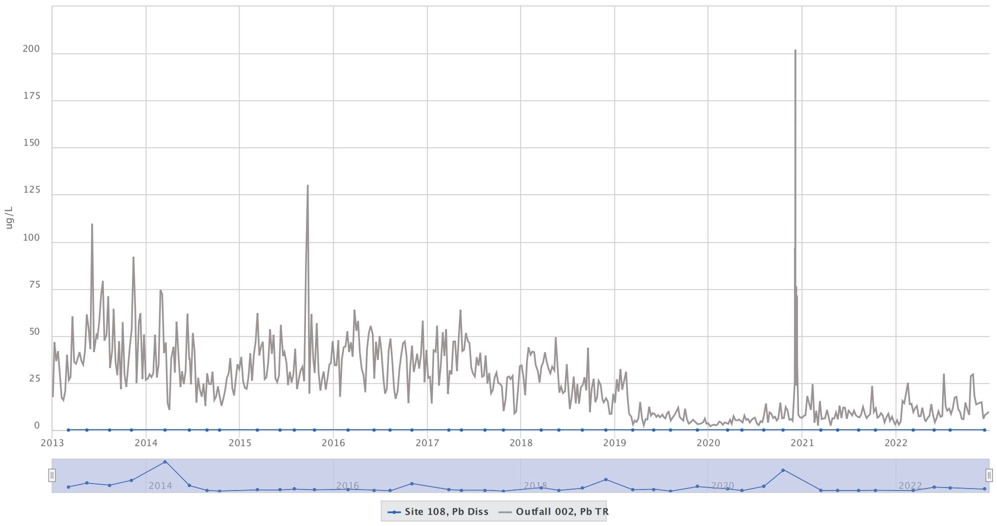


Figure 2-8e. Site 108 and Outfall 002 – Field pH

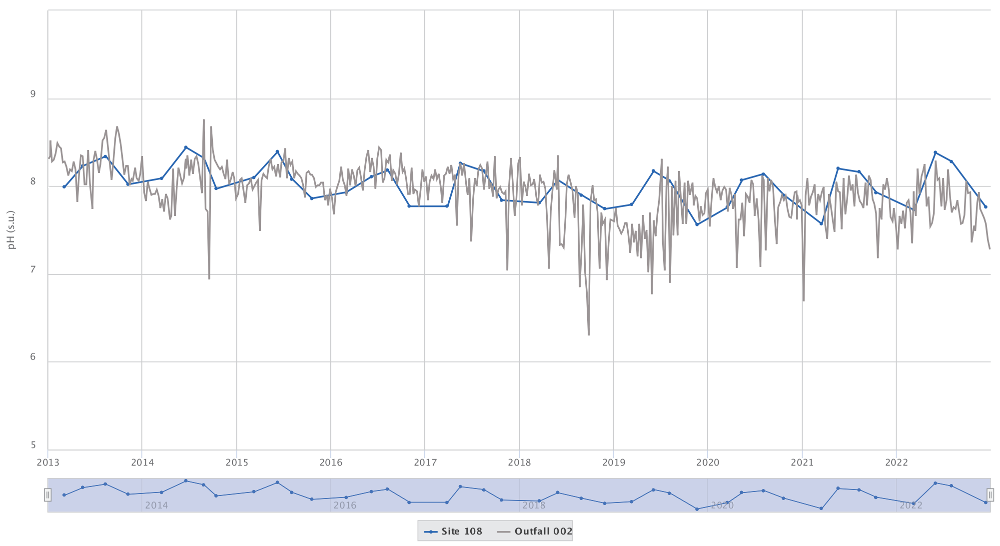


Figure 2-8f. Site 108 and Outfall 002 – Zn

Outfall 002 Daily Max Limit: 1,000 ug/L – Saltwater AWQS: 81.5 ug/L

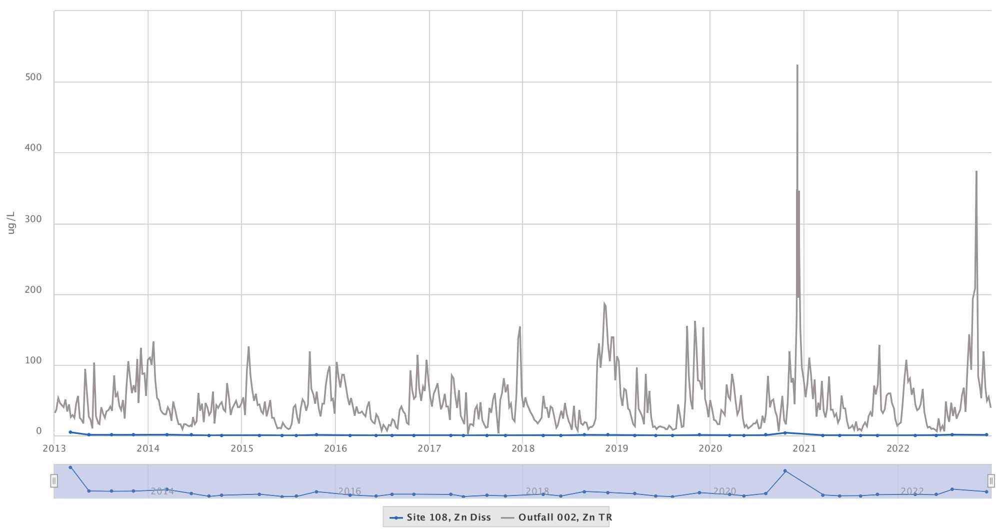


Figure 3-1. Cadmium in Sediment at Site S-1

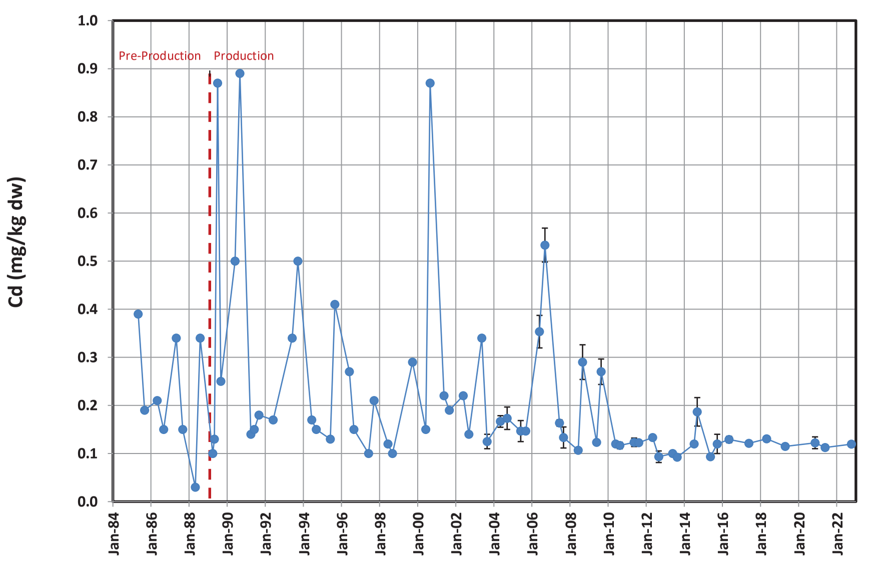


Figure 3-3. Lead in Sediment at Site S-1

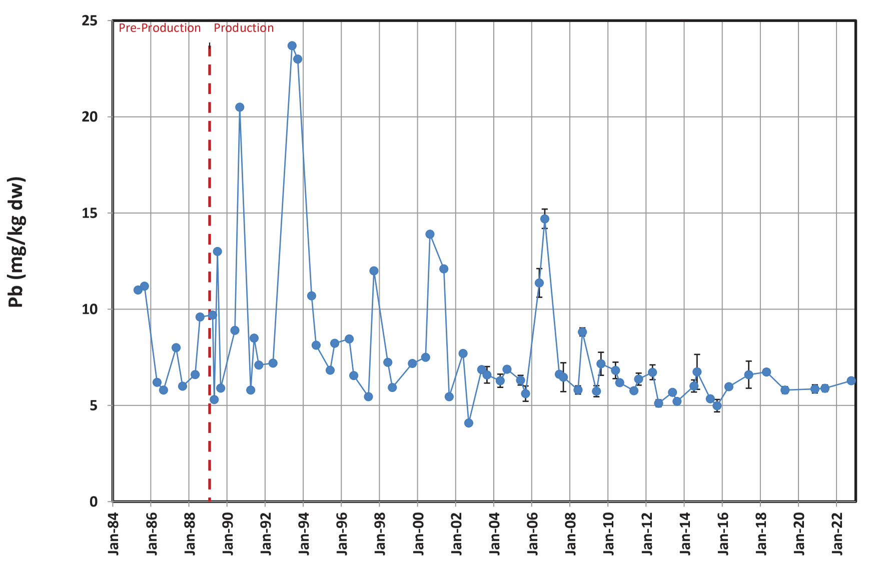


Figure 3-5. Zinc in Sediment at Site S-1

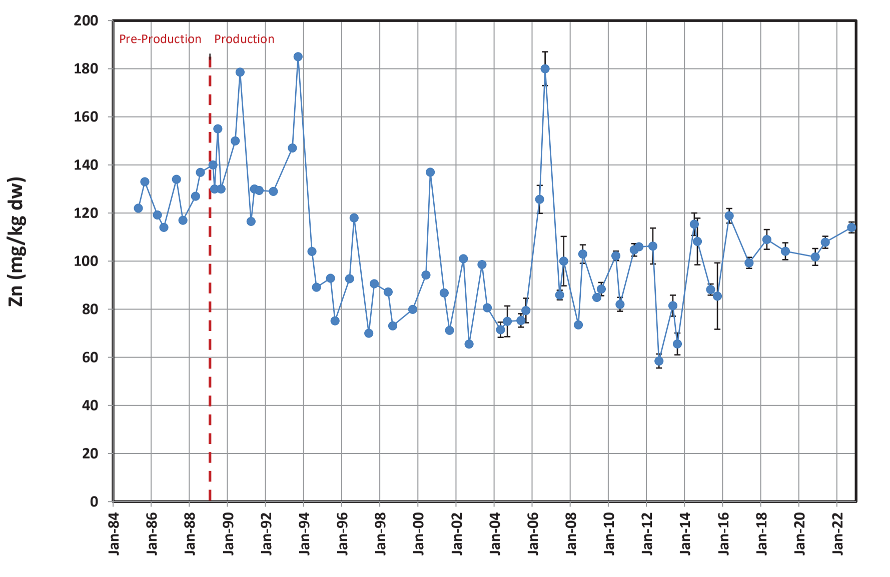


Figure 3-2. Copper in Sediment at Site S-1

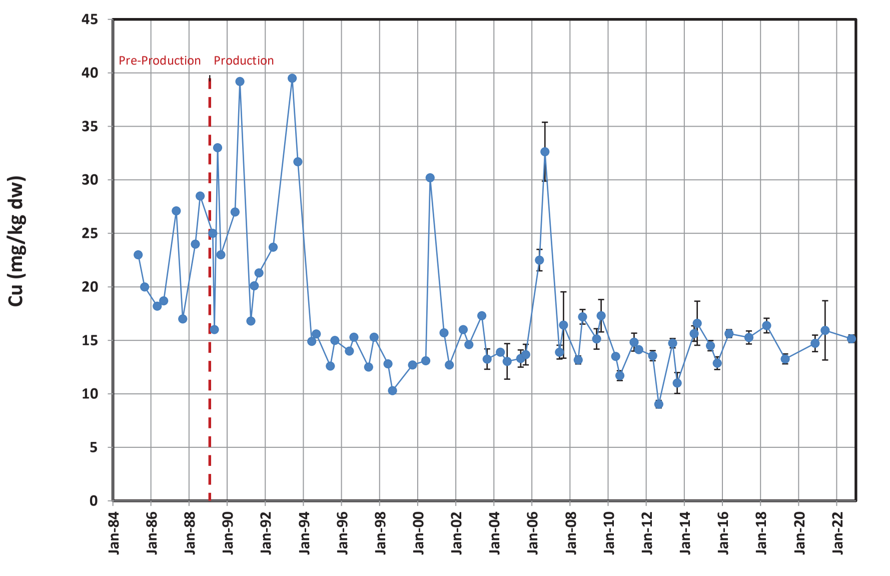


Figure 3-4. Mercury in Sediment at Site S-1

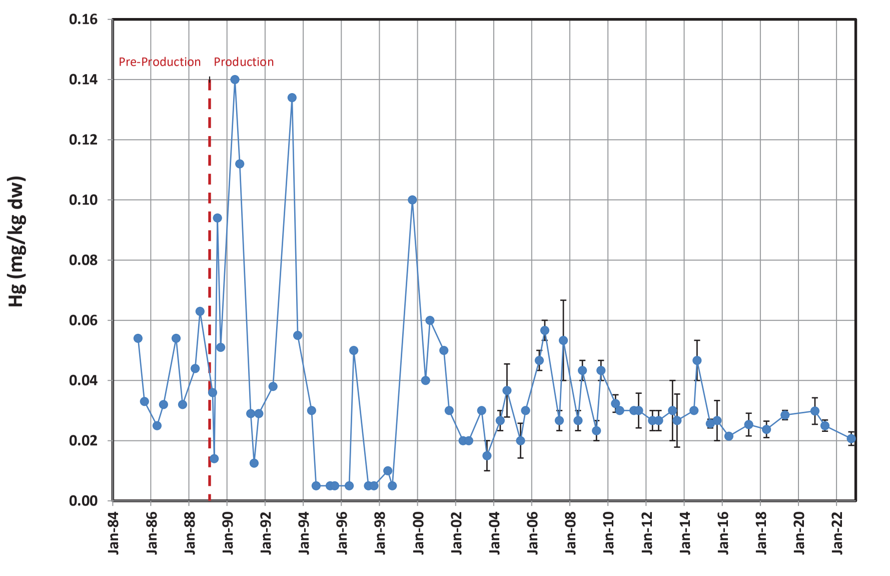


Figure 3-6. Cadmium in Sediment at Site S-2

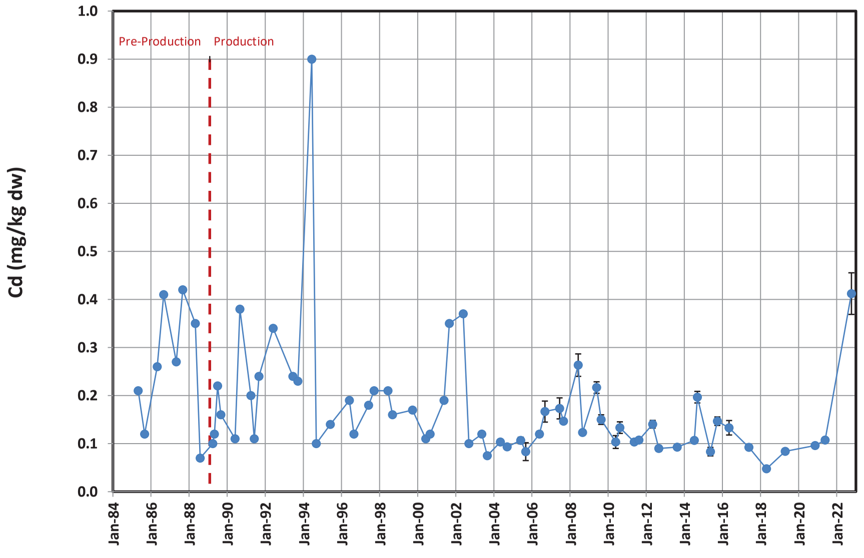


Figure 3-8. Lead in Sediment at Site S-2

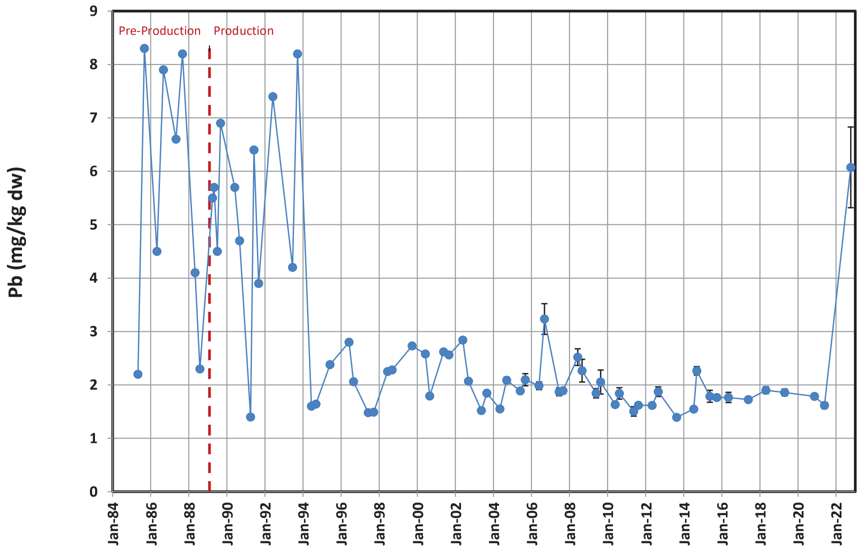


Figure 3-10. Zinc in Sediment at Site S-2

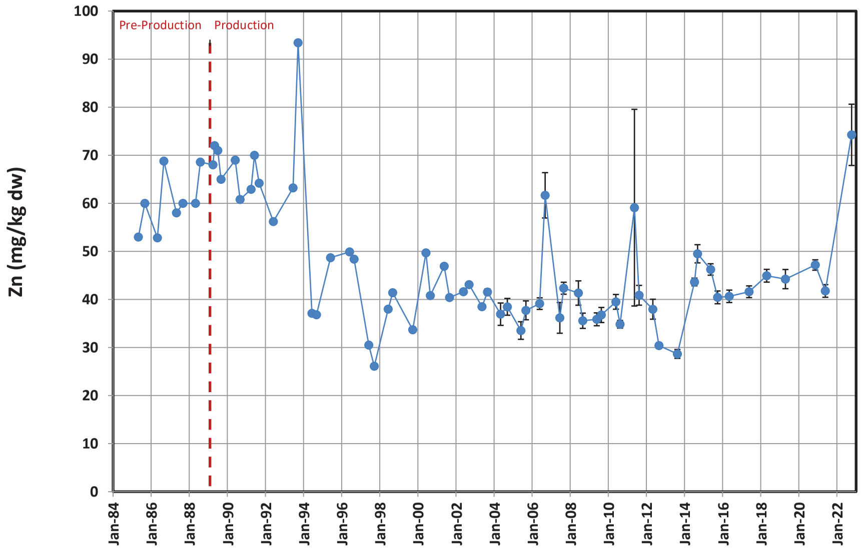


Figure 3-7. Copper in Sediment at Site S-2

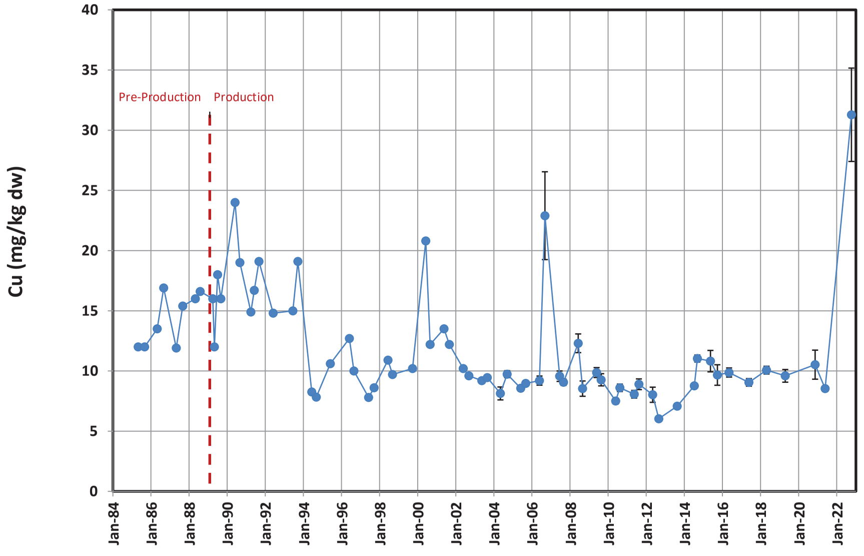
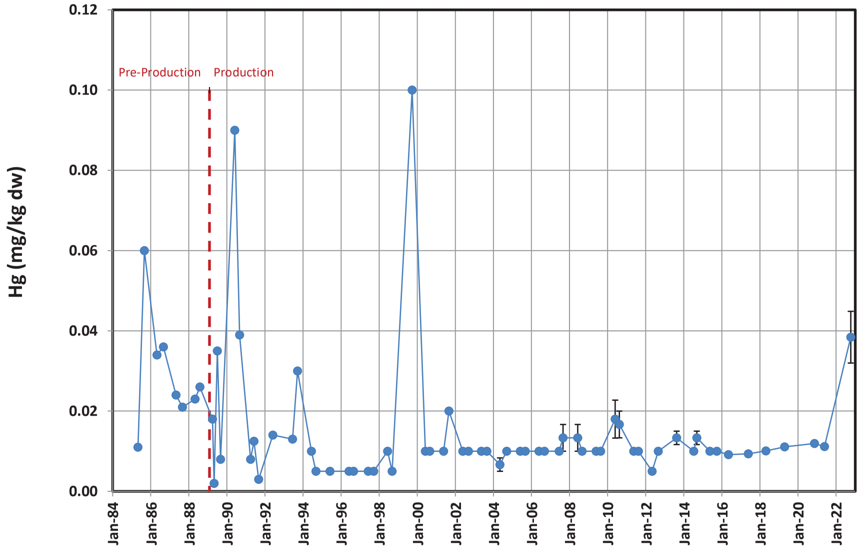


Figure 3-9. Mercury in Sediment at Site S-2



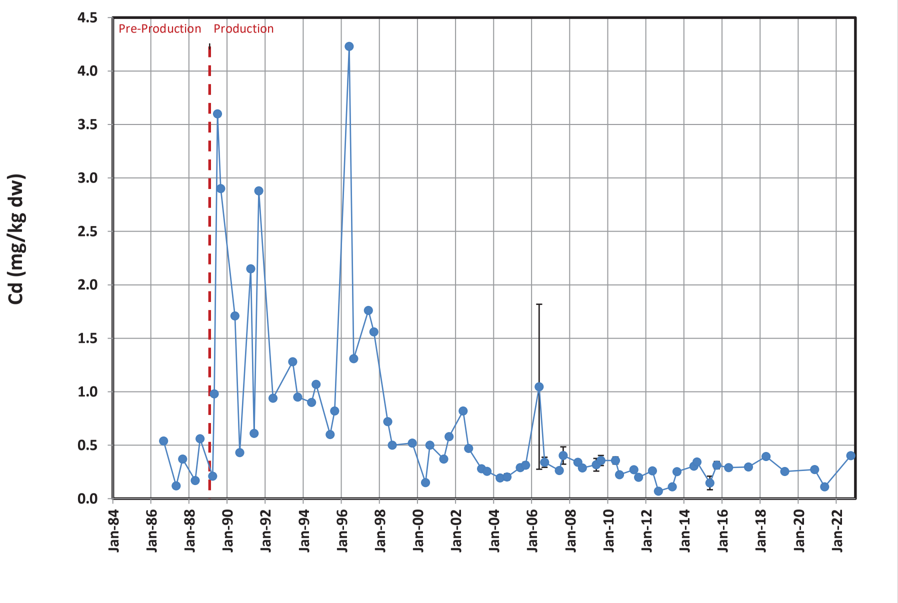


Figure 3-11. Cadmium in Sediment at Site S-4

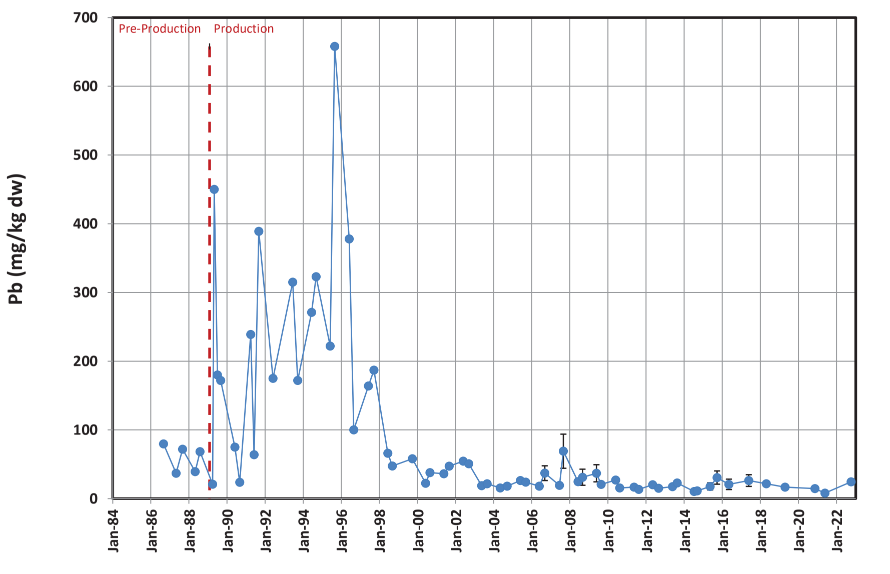


Figure 3-13. Lead in Sediment at Site S-4

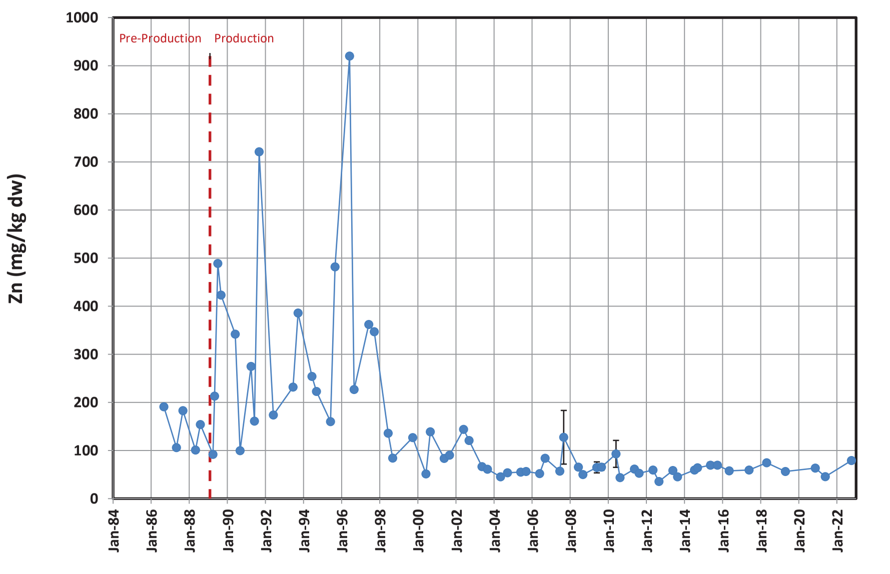


Figure 3-15. Zinc in Sediment at Site S-4

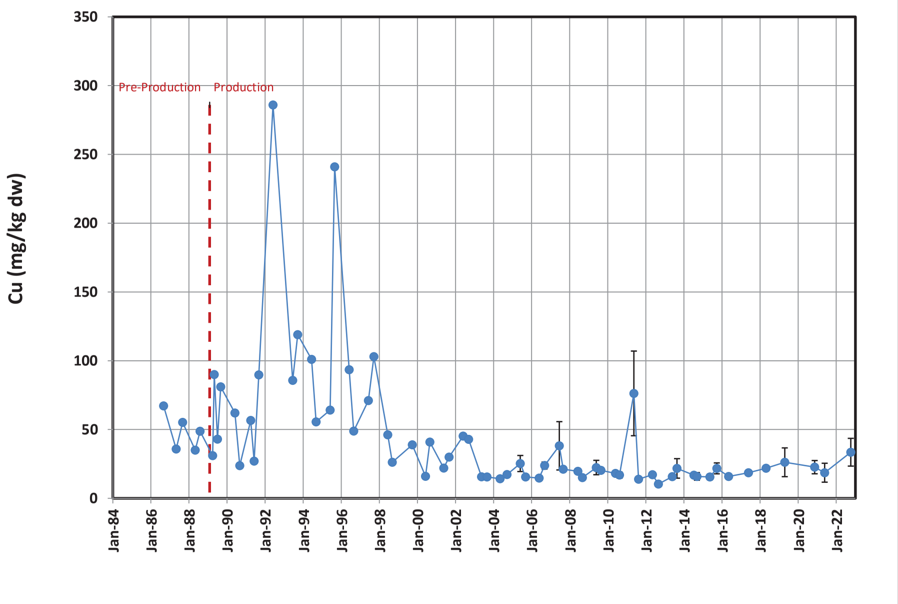


Figure 3-12. Copper in Sediment at Site S-4

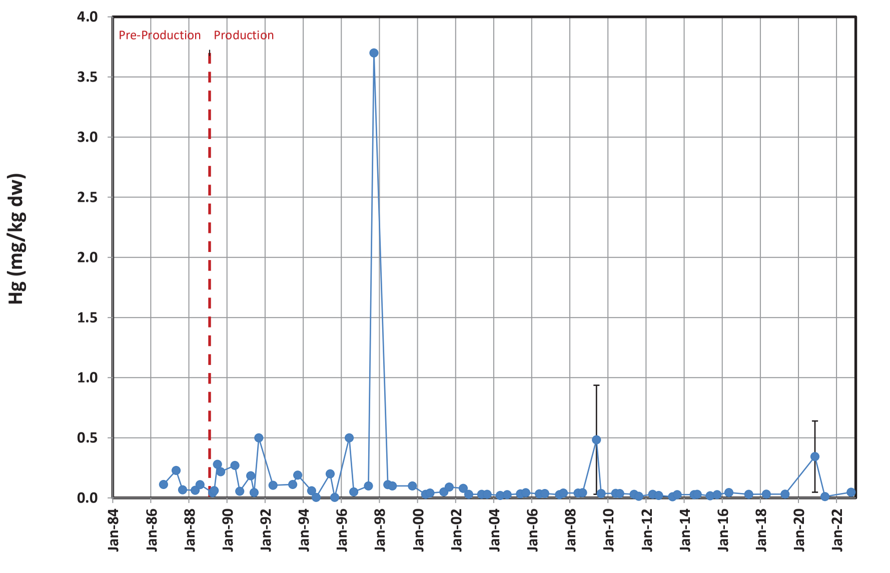


Figure 3-14. Mercury in Sediment at Site S-4

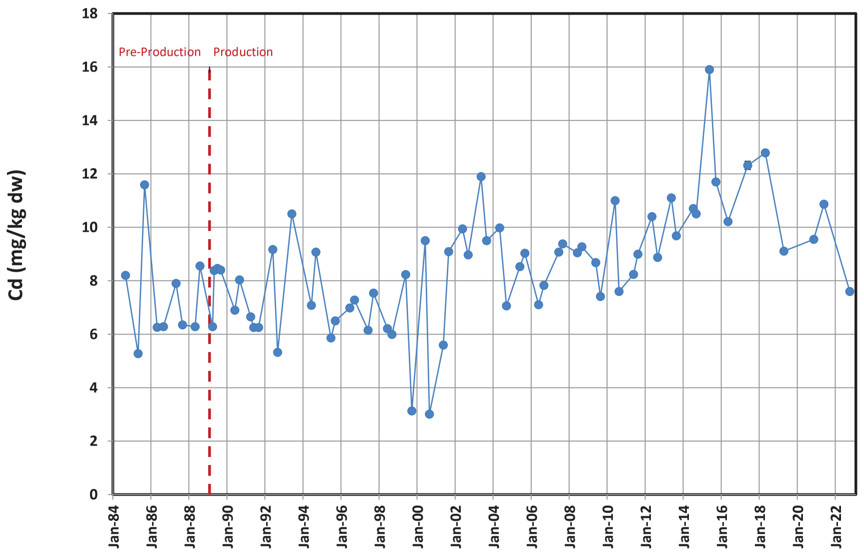


Figure 4-1. Cadmium in Mussels at Site STN-1

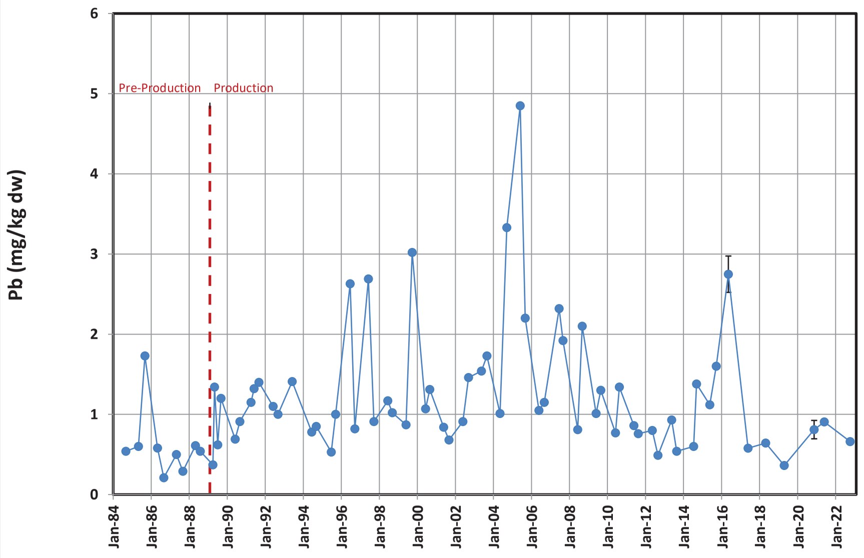


Figure 4-3. Lead in Mussels at Site STN-1

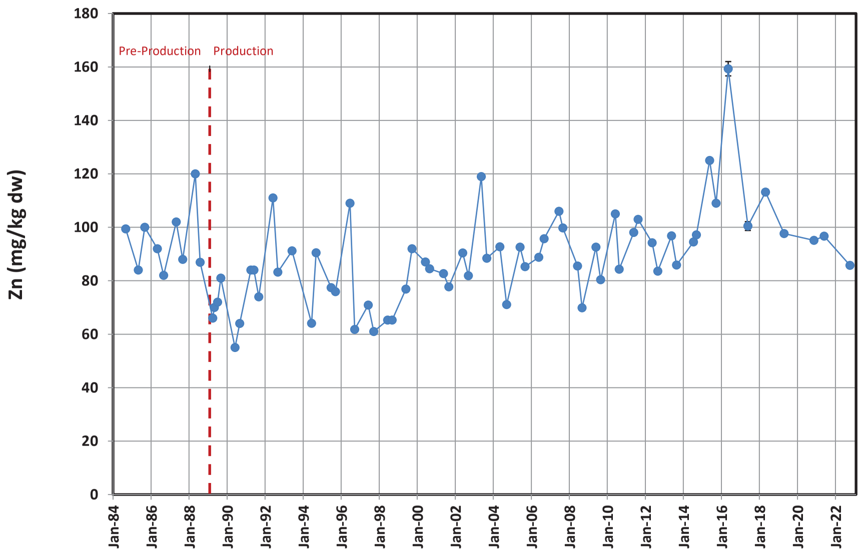


Figure 4-5. Zinc in Mussels at Site STN-1

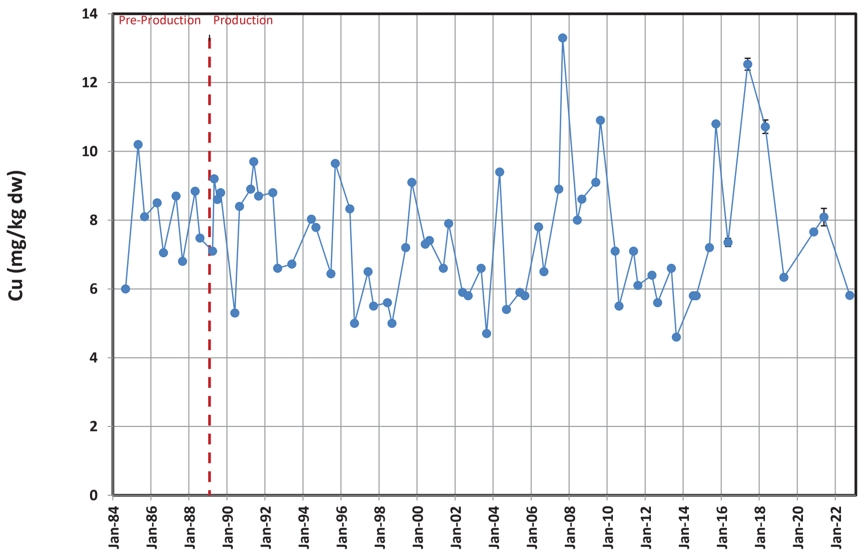


Figure 4-2. Copper in Mussels at Site STN-1

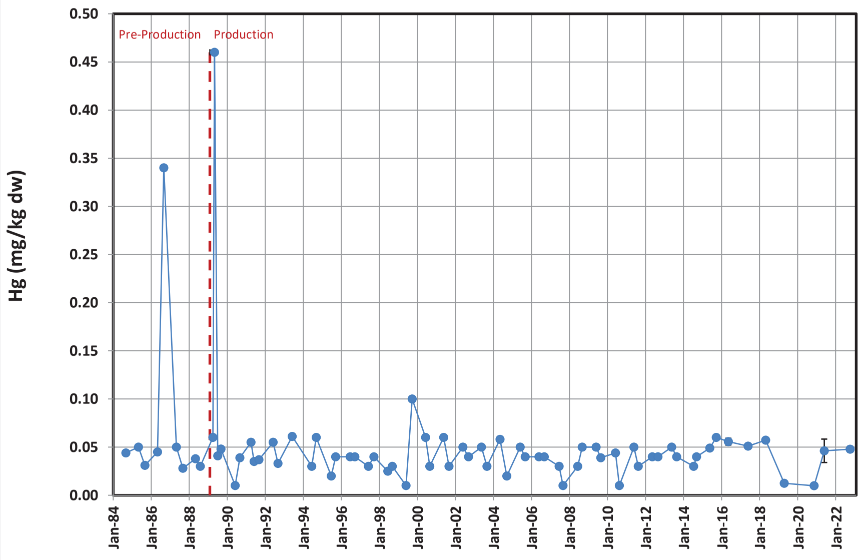


Figure 4-4. Mercury in Mussels at Site STN-1

Figure 4-6. Cadmium in Mussels at Site STN-2

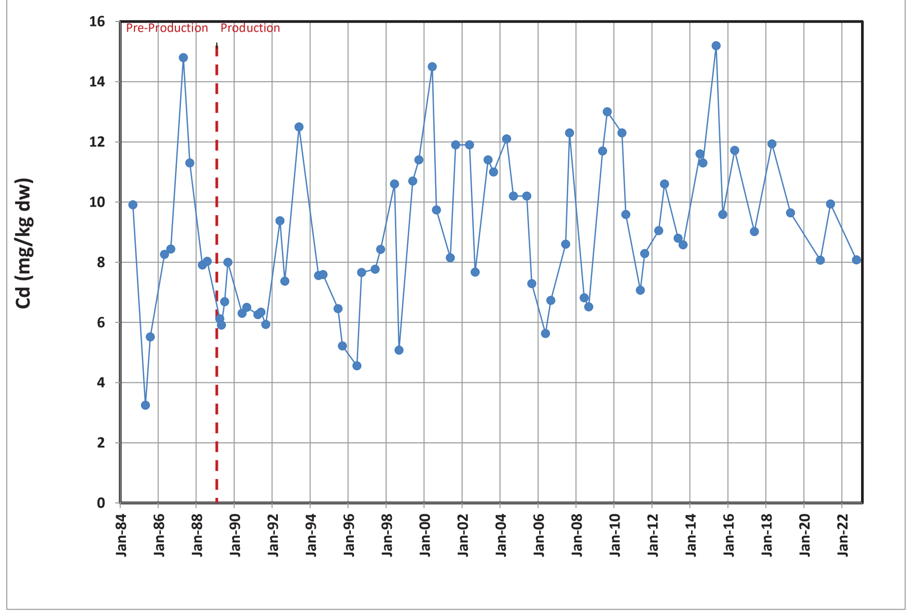


Figure 4-7. Copper in Mussels at Site STN-2

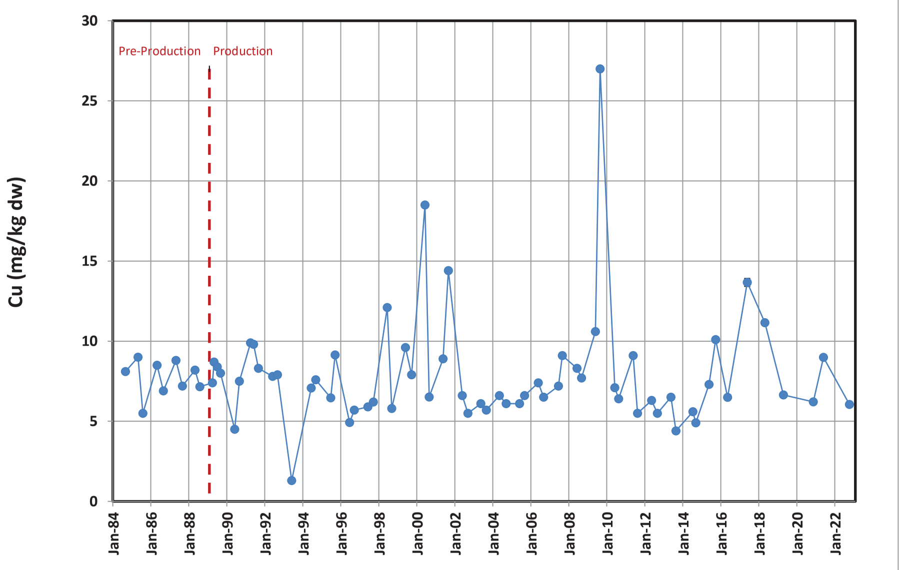


Figure 4-8. Lead in Mussels at Site STN-2

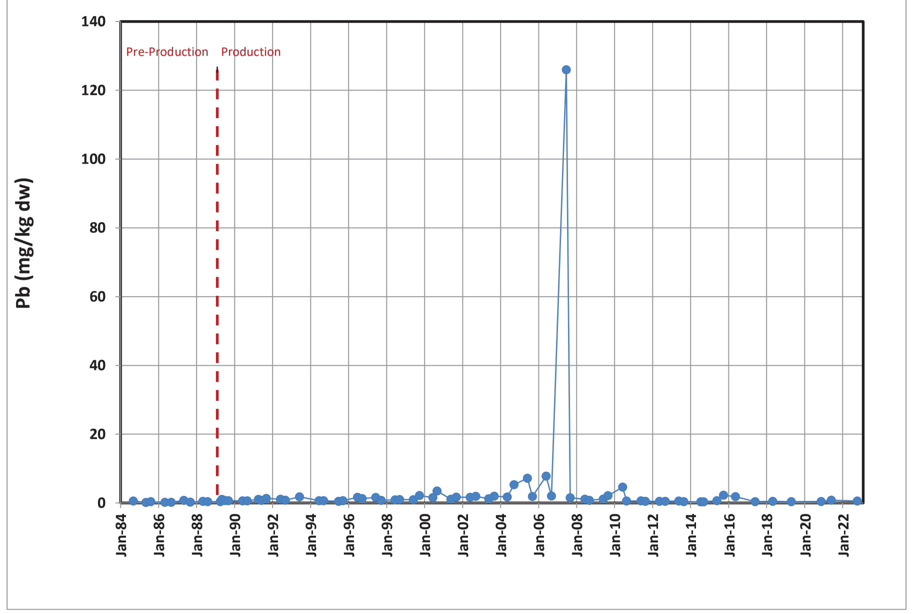


Figure 4-9. Mercury in Mussels at Site STN-2

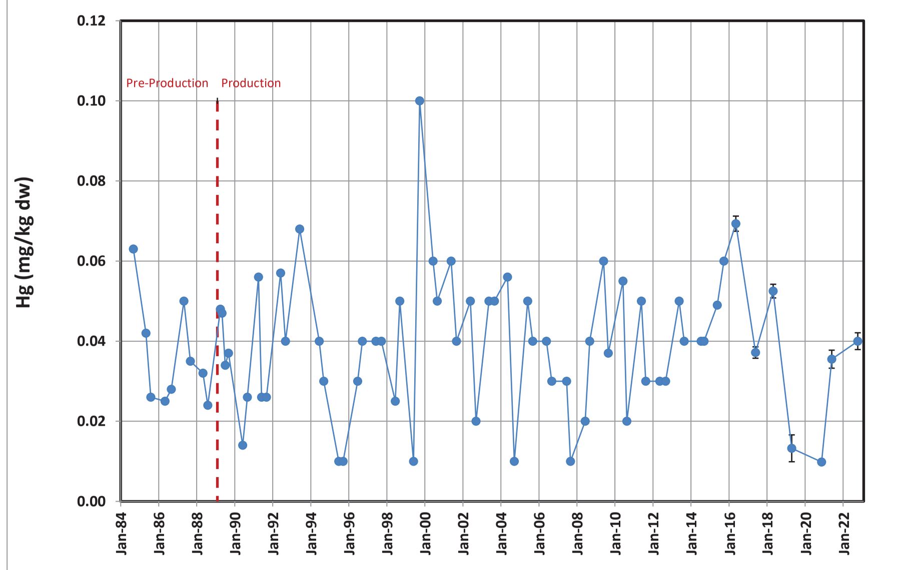
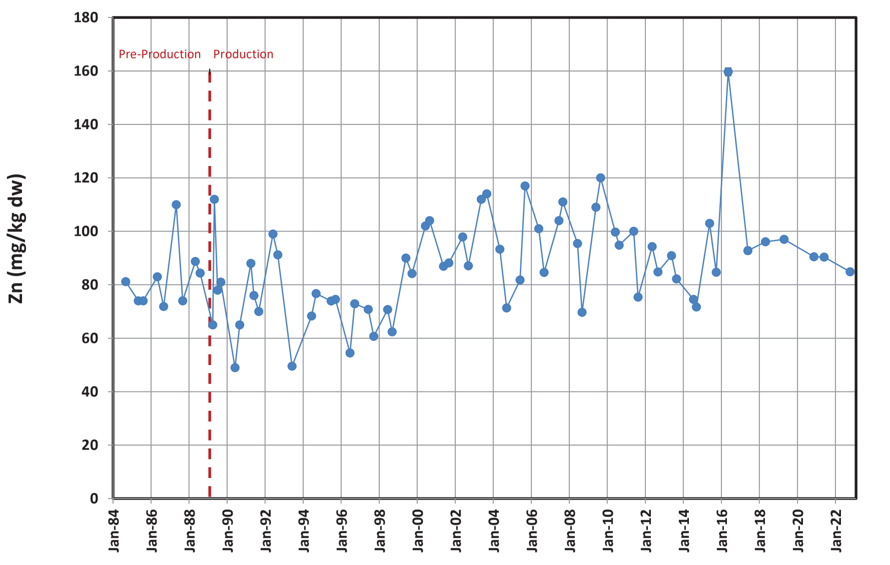


Figure 4-10. Zinc in Mussels at Site STN-2



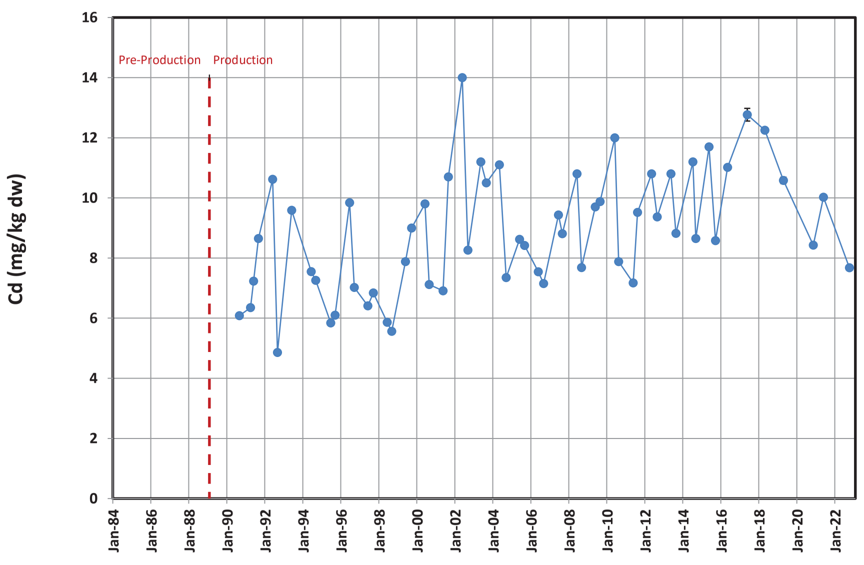


Figure 4-11. Cadmium in Mussels at Site STN-3

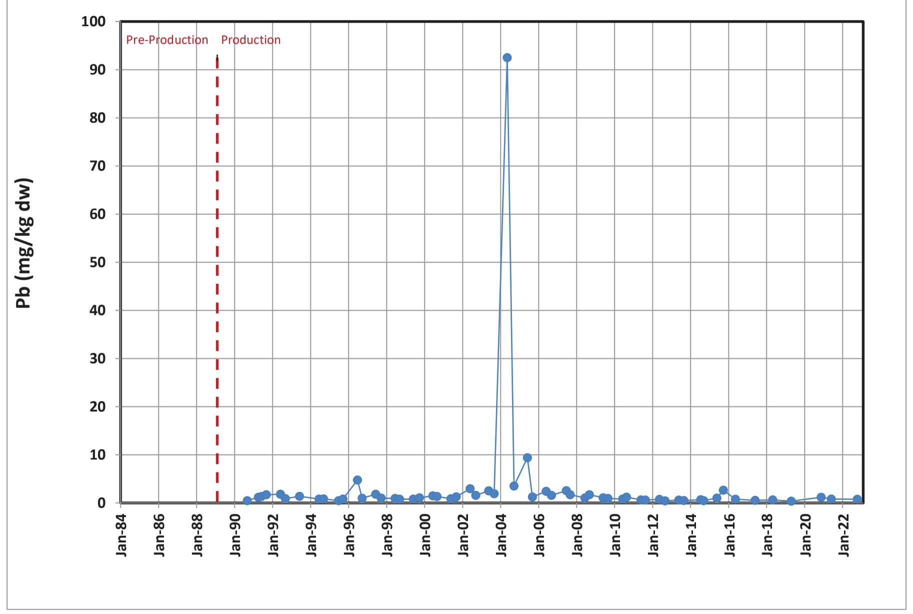


Figure 4-13. Lead in Mussels at Site STN-3

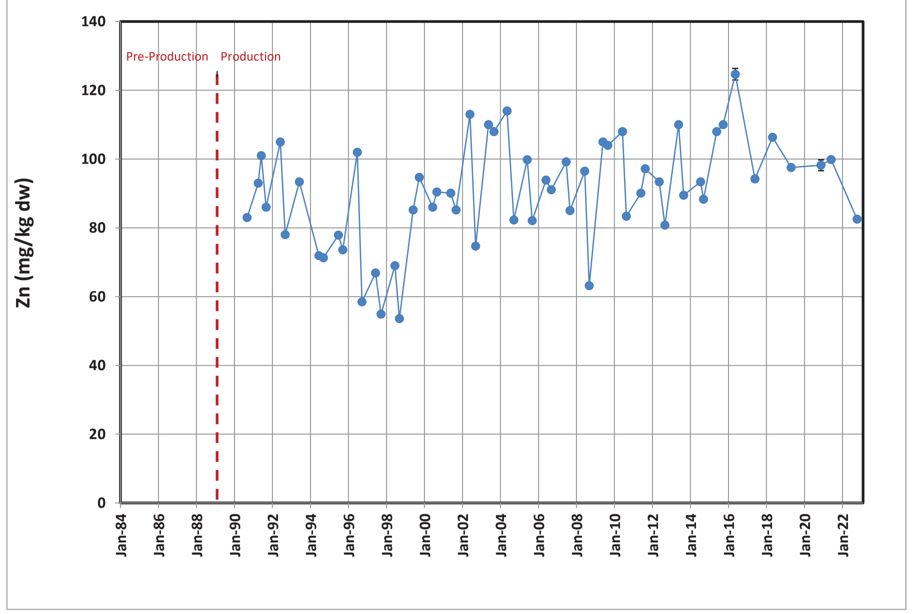


Figure 4-15. Zinc in Mussels at Site STN-3

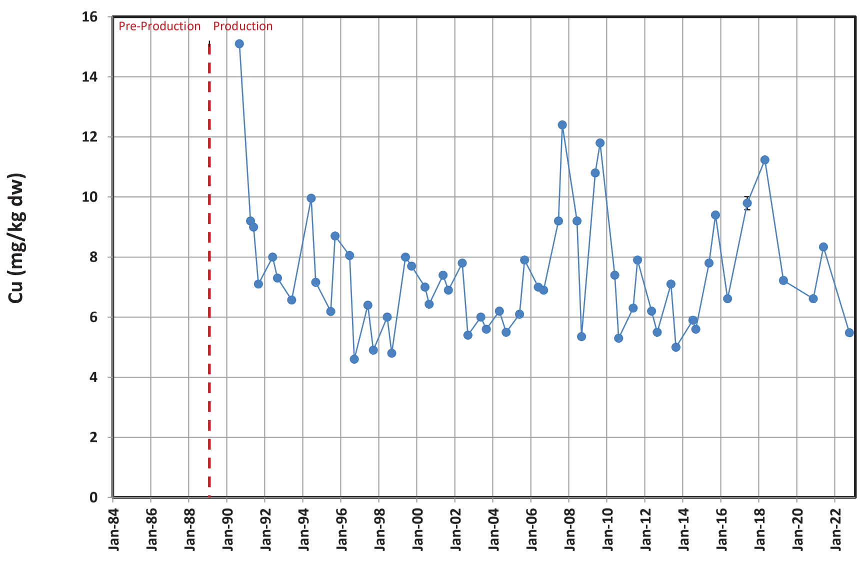


Figure 4-12. Copper in Mussels at Site STN-3

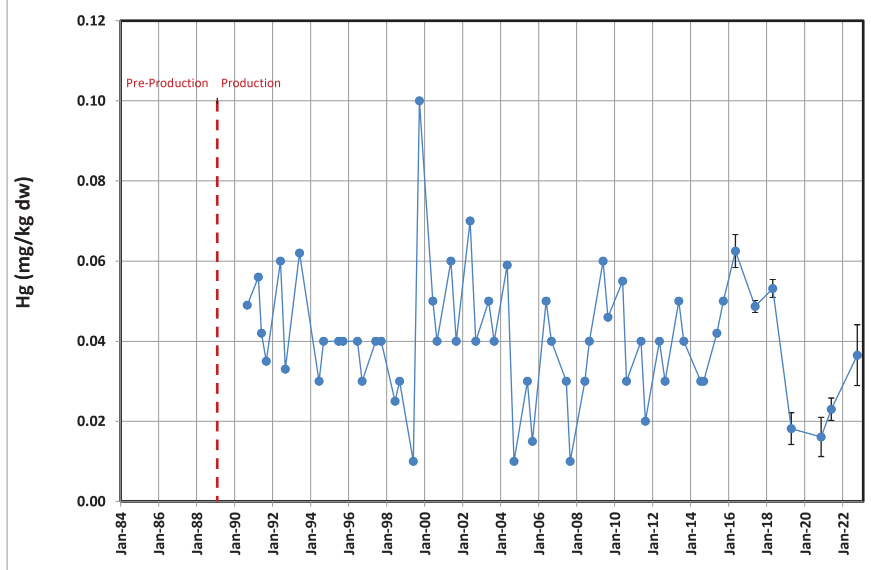


Figure 4-14. Mercury in Mussels at Site STN-3

Figure 4-21. Cadmium in Nephtys at Site S-1

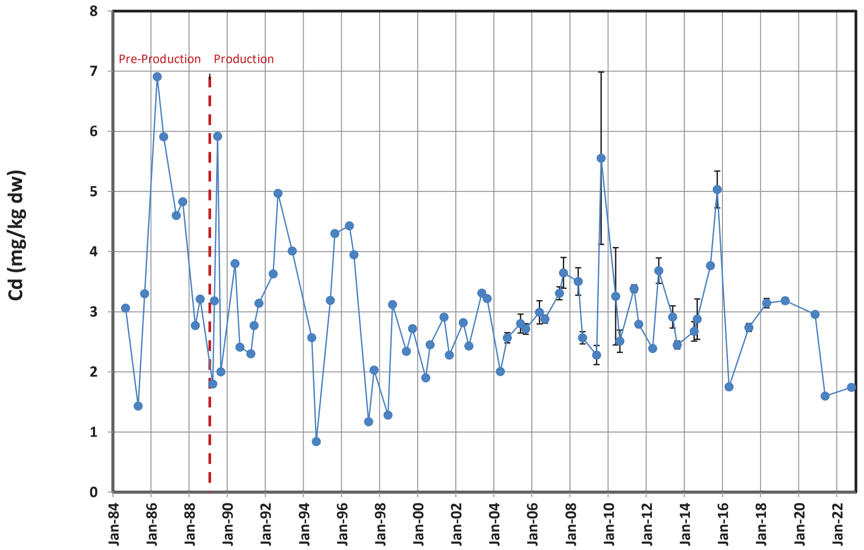


Figure 4-23. Lead in Nephtys at Site S-1

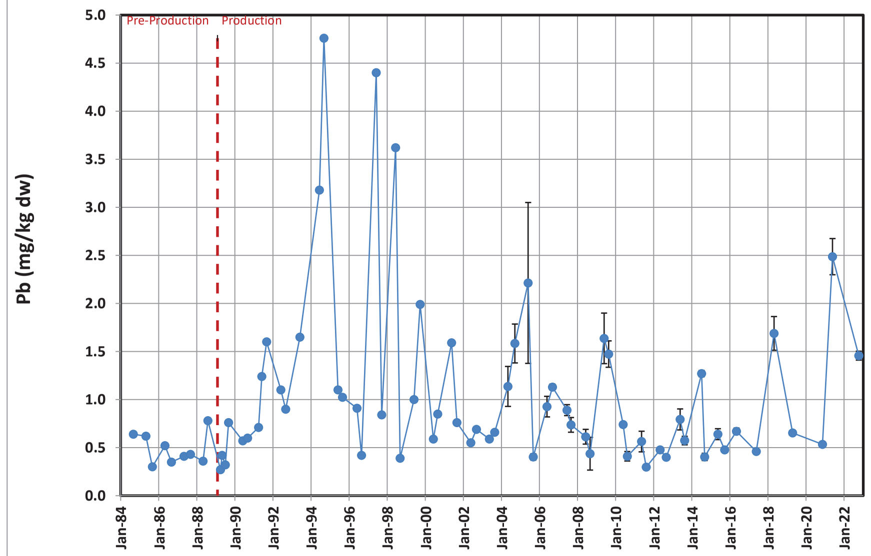


Figure 4-25. Zinc in Nephtys at Site S-1

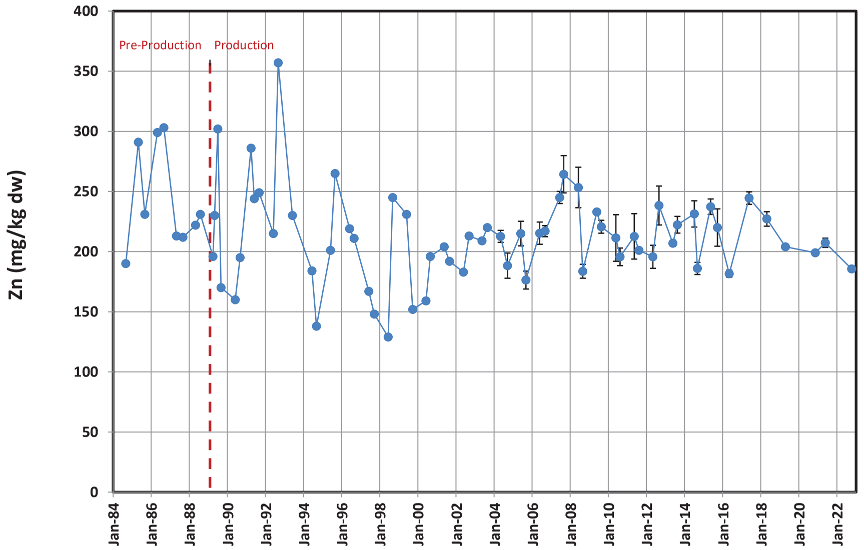


Figure 4-22. Copper in Nephtys at Site S-1

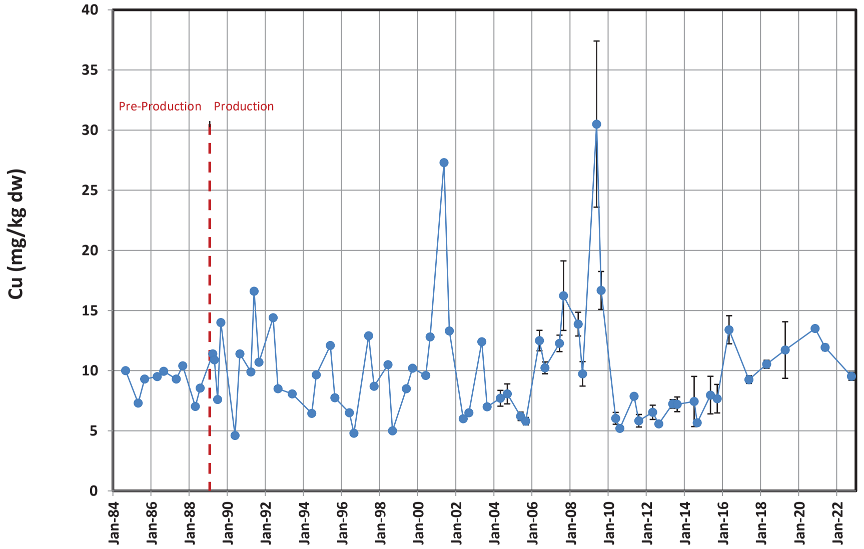


Figure 4-24. Mercury in Nephtys at Site S-1

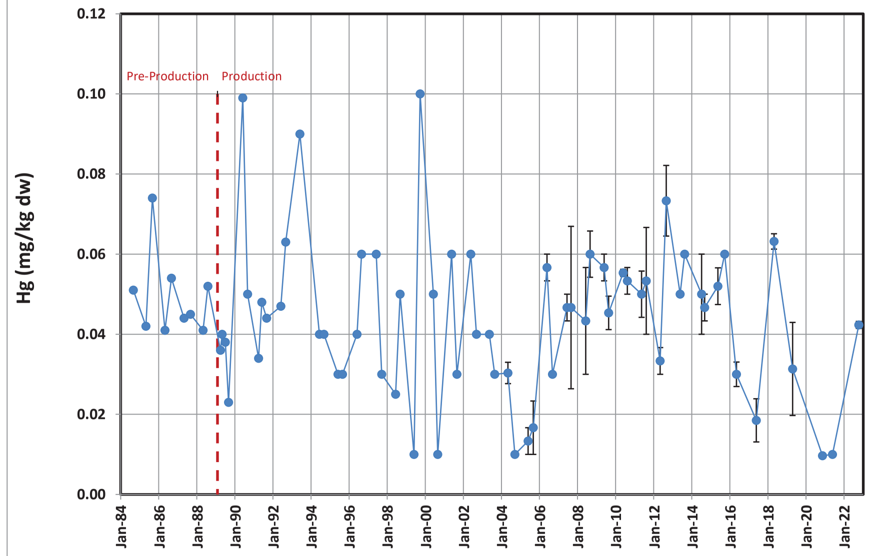


Figure 4-26. Cadmium in Nephtys at Site S-2

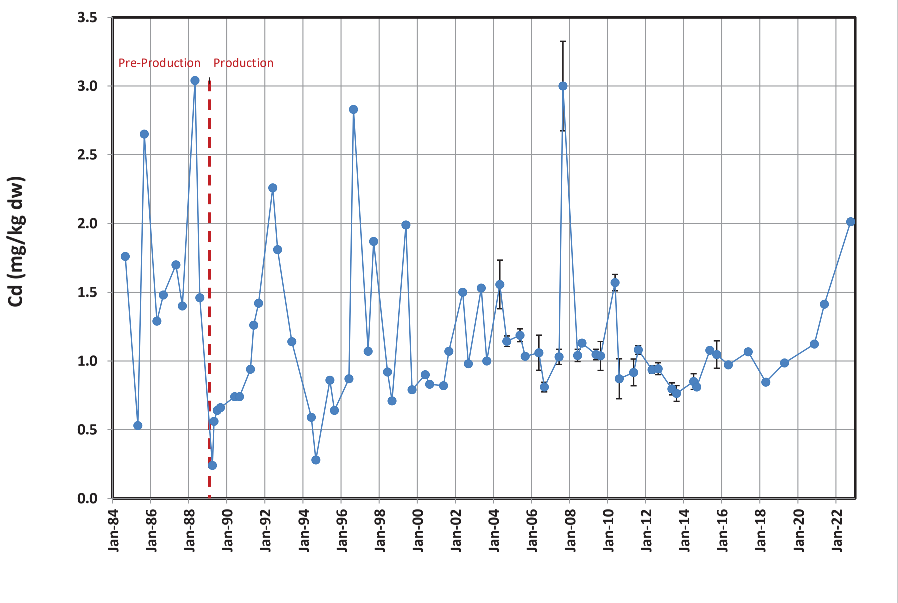


Figure 4-28. Lead in Nephtys at Site S-2

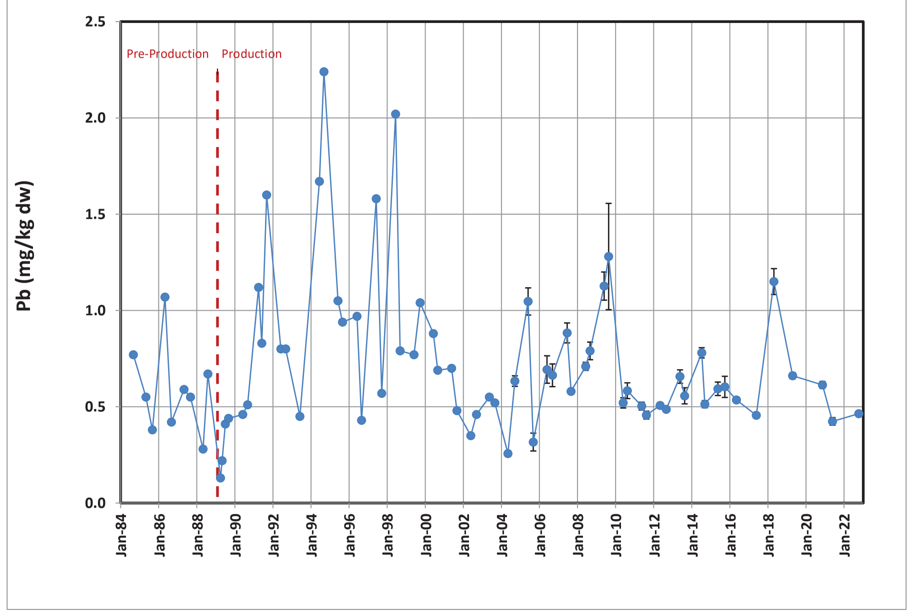


Figure 4-30. Zinc in Nephtys at Site S-2

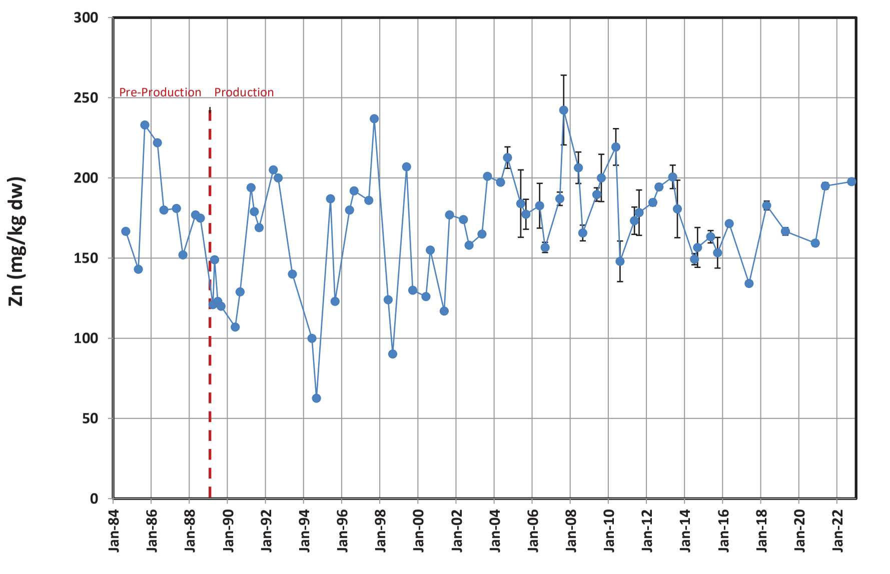


Figure 4-27. Copper in Nephtys at Site S-2

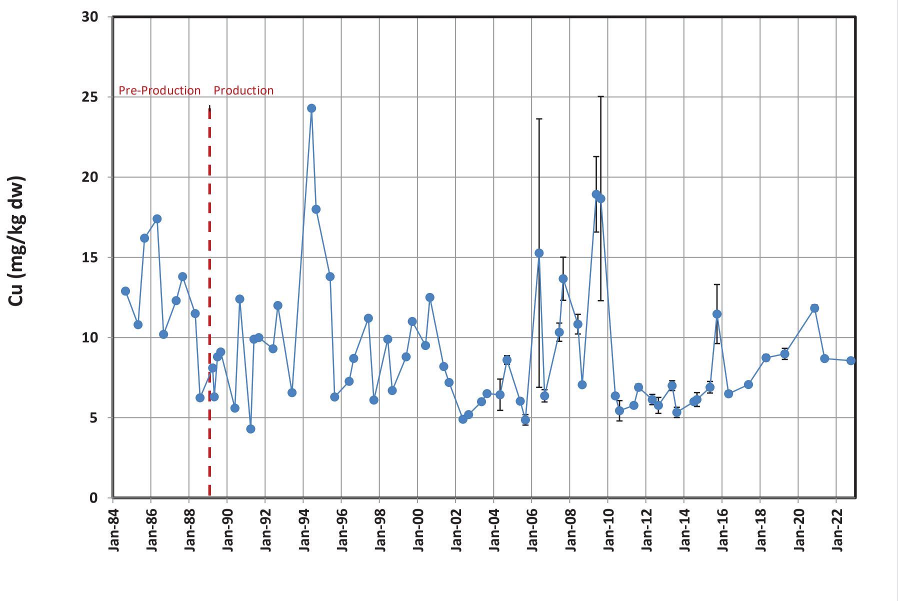


Figure 4-29. Mercury in Nephtys at Site S-2

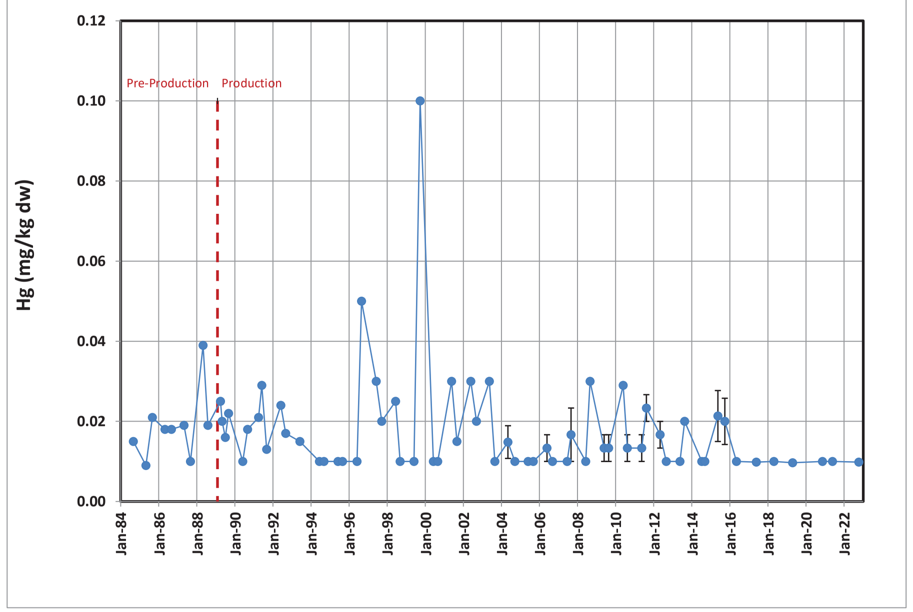


Figure 4-31. Cadmium in Nephtys at Site S-4

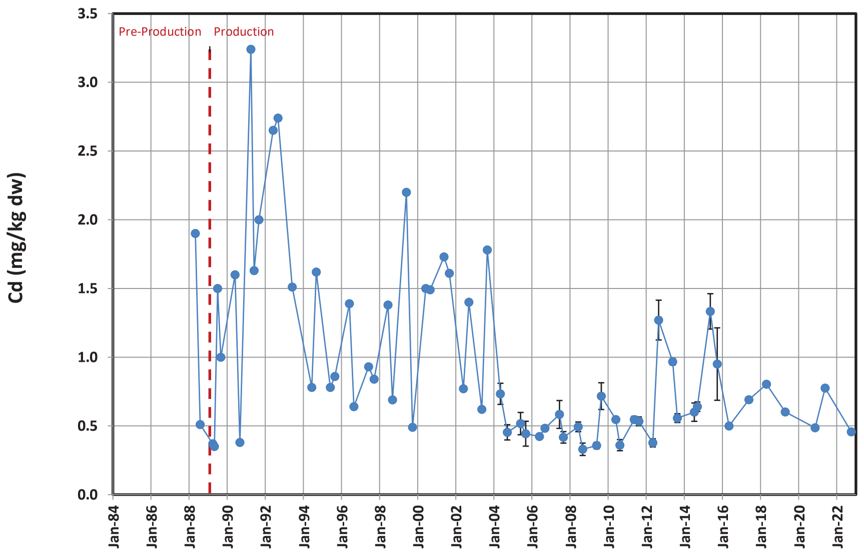


Figure 4-33. Lead in Nephtys at Site S-4

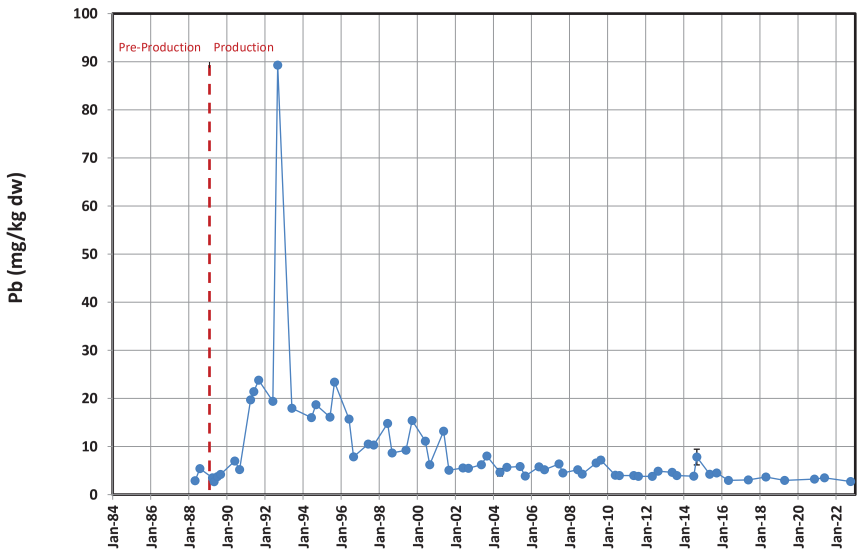


Figure 4-35. Zinc in Nephtys at Site S-4

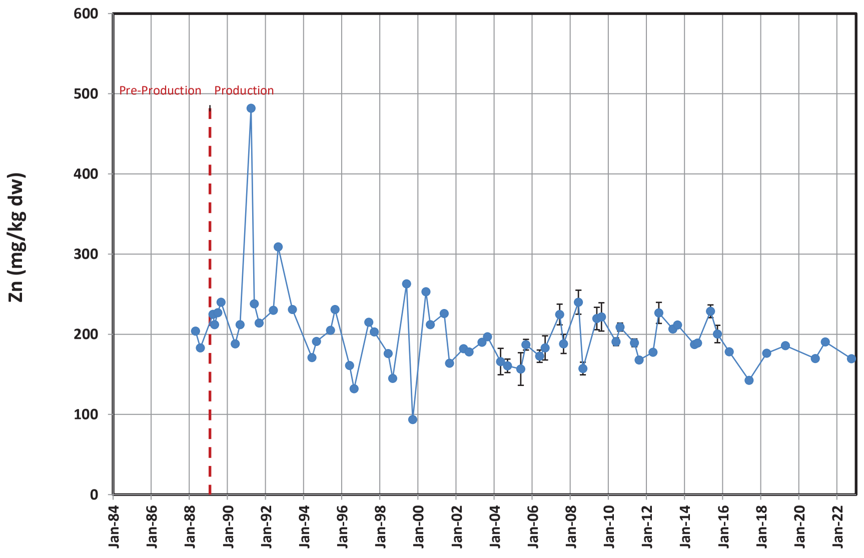


Figure 4-32. Copper in Nephtys at Site S-4

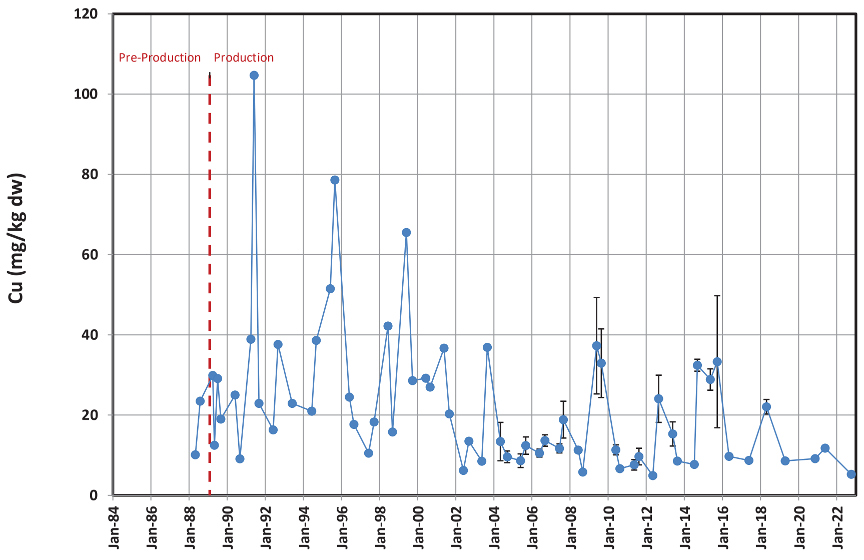
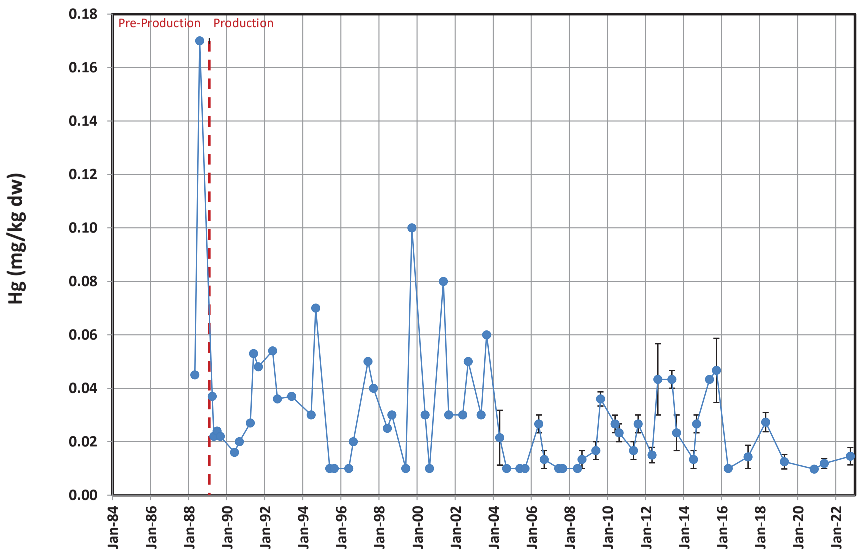


Figure 4-34. Mercury in Nephtys at Site S-4



7. APPENDICES

7.1. Appendix A - Outfall Survey Report and Video Footage

7.2. Appendix B - Historical Hawk Inlet Data

MEMORANDUM

State of Alaska

Department of Fish and Game
Division of Commercial Fisheries

TO: file

DATE: December 15, 2016

PHONE NO: 465-4228

FROM: Kyle Hebert
Dive Fisheries Research Supervisor
Region I

SUBJECT: Hawk Inlet Intertidal Clam Investigation

In 2014, during the environmental impact statement development for Hecla Greens Creek Mining Company's proposed tailings disposal facility expansion, Mr. William Brent raised a concern about low clam abundance in Piledriver Cove, Hawk Inlet, where he resides. Hecla's Greens Creek Mine facilities are located in Hawk Inlet, within six kms north of Piledriver Cove. I discussed the concern with Kate Kanouse (ADF&G Habitat Division) and Will Collingwood (ADEC Division of Water), and agreed to perform a casual investigation of clams present in Piledriver Cove if time and staff allowed.

Purpose

The purpose of this investigation was to qualitatively characterize the intertidal clam community in Piledriver Cove and conduct a similar investigation nearby at the mouth of Greens Creek, also in Hawk Inlet.

Methods

On May 6, 2016, ADF&G Division of Commercial Fisheries staff conducted a one-day investigation near the mouth of Hawk Inlet in Piledriver Cove, and at the Greens Creek delta approximately 1.5 kms north of Piledriver Cove, to evaluate presence of intertidal clams (Figure 1). The investigation was conducted by department divers stationed aboard ADF&G's R/V Kestrel, while in between herring spawn deposition dive surveys.

Although we did not design a survey that is capable of producing data for use in rigorous statistical analysis, the investigation involved a series of transects with the intent to provide a systematic mechanism to count clams and characterize clam distribution within the study sites. We completed nine transects during the investigation, five transects in the northern half of Piledriver Cove, and four transects in the delta south of Green's Creek (Table 1). All transects were located in the intertidal zone at the marine terminus of a stream. Substrate types were similar at both study sites and dominated by mud, sand, and gravel.

Transects were generally oriented in an east-west direction and conducted at -3.0 tidal stage. Due to the low tide stage, diving was not necessary to thoroughly examine intertidal clam habitat. Subtidal habitat was not explored. Transects were completed by laying a 0.1 m^2 plastic sampling frame spaced equidistant within each transect, and recording the estimated elevation (mean lower low water), the number of clams by species, and substrate type. After positioning a frame, a shovel or rake was used to excavate the substrate to a depth of at least 30 cm. The sampling frame was spaced within each transect either 10, 20 or 30 m apart, depending on the frequency of clams observed along neighboring transects. For example, toward the mouth (i.e. northern side) of Piledriver Cove, the first transects were conducted with 10-m intervals between frames where clam habitat appeared most suitable. Consequently, for transects at the head of the bay where clam habitat was less optimal, the frame spacing interval was increased to reduce the survey time in areas expected to yield fewer clams.

Results and Discussion

Several types of clams and cockles were observed during the investigation: butter clams *Saximdomus giganteus,* venus clams *Humilaria kennerleyi* and *Compsomyax subdiaphana*, Pacific littleneck (or "steamer") clams P*rotothaca staminea*, pink neck clams *Mactromeris polynyma*, and cockles *Clinocardium nuttalli*. We found few clams (Table 2) and the density of combined clam/cockle species in Piledriver Cove was approximately 1.55 /m^2 (Table 3). The approximate density of individual clam types ranged from 0.04/m^2 (pink neck clams) to 3.99/m^2 (butter/venus clams). The term "approximated" is used rather than "estimated", because the lack of a proper survey design limits the degree to which conclusions can be made about accuracy or variation of the results.

No clams were observed at the Greens Creek delta study site. As there are no prior data available, it is unknown if clams ever resided there. Although the substrate appeared to be consistent with hard shell clam habitat, it generally consisted of less mud and more gravel than substrate at the Piledriver Cove study site. It is possible that despite the close proximity of the two sites and the apparent similarities of substrate, the difference in clam abundance is due to other physical or environmental factors that were not measured–such as salinity concentration, which governs clam/cockle habitat suitability.

Table 1.–Coordinates (Datum WGS1984) for transect locations at study sites near the entrance to Hawk Inlet, Admiralty Island, Southeast Alaska.

Transect	Site	Latitude	Longitude
1 start	Piledriver Cove	58.0852	-134.7764
2 start	Piledriver Cove	58.0848	-134.7714
2 stop	Piledriver Cove	58.0848	-134.7768
3 start	Piledriver Cove	58.0844	-134.7754
3 stop	Piledriver Cove	58.0842	-134.7716
4 start	Piledriver Cove	58.0833	-134.7713
4 stop	Piledriver Cove	58.0828	-134.7779
5 start	Piledriver Cove	58.0824	-134.7714
5 stop	Piledriver Cove	58.0819	-134.7773
1 start	Greens Creek	58.0989	-134.7651
2 start	Greens Creek	58.0996	-134.7660
2 stop	Greens Creek	58.1003	-134.7642
3 start	Greens Creek	58.1004	-134.7665
4 start	Greens Creek	58.1007	-134.7679
4 stop	Greens Creek	58.1013	-134.7671

Table 2.–Total counts of clams observed along transects surveyed near the entrance of Hawk Inlet, Admiralty Island, Southeast Alaska.

Survey site	Transect	Butter/venus clams	Littleneck clams	Pink neck	Cockles	Total clams	Frame count	Frame spacing (m)	Transect length (m)
Piledriver Cove	1	3	4	0	0	7	7	10	70
Piledriver Cove	2	18	10	1	8	37	50	10	500
Piledriver Cove	3	6	1	0	0	7	26	10	260
Piledriver Cove	4	11	0	0	0	11	12	10	120
Piledriver Cove	5	1	2	0	0	3	17	20	340
Subtotal		39	17	1	8	65	112	60	1,290
Greens Creek	1	0	0	0	0	0	2	30	60
Greens Creek	2	0	0	0	0	0	8	30	240
Greens Creek	3	0	0	0	0	0	6	30	180
Greens Creek	4	0	0	0	0	0	5	30	150
Subtotal		0	0	0	0	0	21		

Table 3.–Mean density of clams (per m^2) within and among transects surveyed near the entrance of Hawk Inlet, Admiralty Island, Southeast Alaska.

Survey site	Transect	Butter/venus clams	Littleneck clams	Pink neck	Cockles	Mean density	Overall density
Piledriver Cove	1	4.29	5.71	0.00	0.00	2.50	
Piledriver Cove	2	3.60	2.00	0.20	1.60	1.85	
Piledriver Cove	3	2.31	0.38	0.00	0.00	0.67	
Piledriver Cove	4	9.17	0.00	0.00	0.00	2.29	
Piledriver Cove	5	0.59	1.18	0.00	0.00	0.44	
Mean density		3.99	1.86	0.04	0.32	1.55	1.55
Greens Creek	1	0.00	0.00	0.00	0.00	0.00	
Greens Creek	2	0.00	0.00	0.00	0.00	0.00	
Greens Creek	3	0.00	0.00	0.00	0.00	0.00	
Greens Creek	4	0.00	0.00	0.00	0.00	0.00	
Mean density		0.00	0.00	0.00	0.00	0.00	0.00

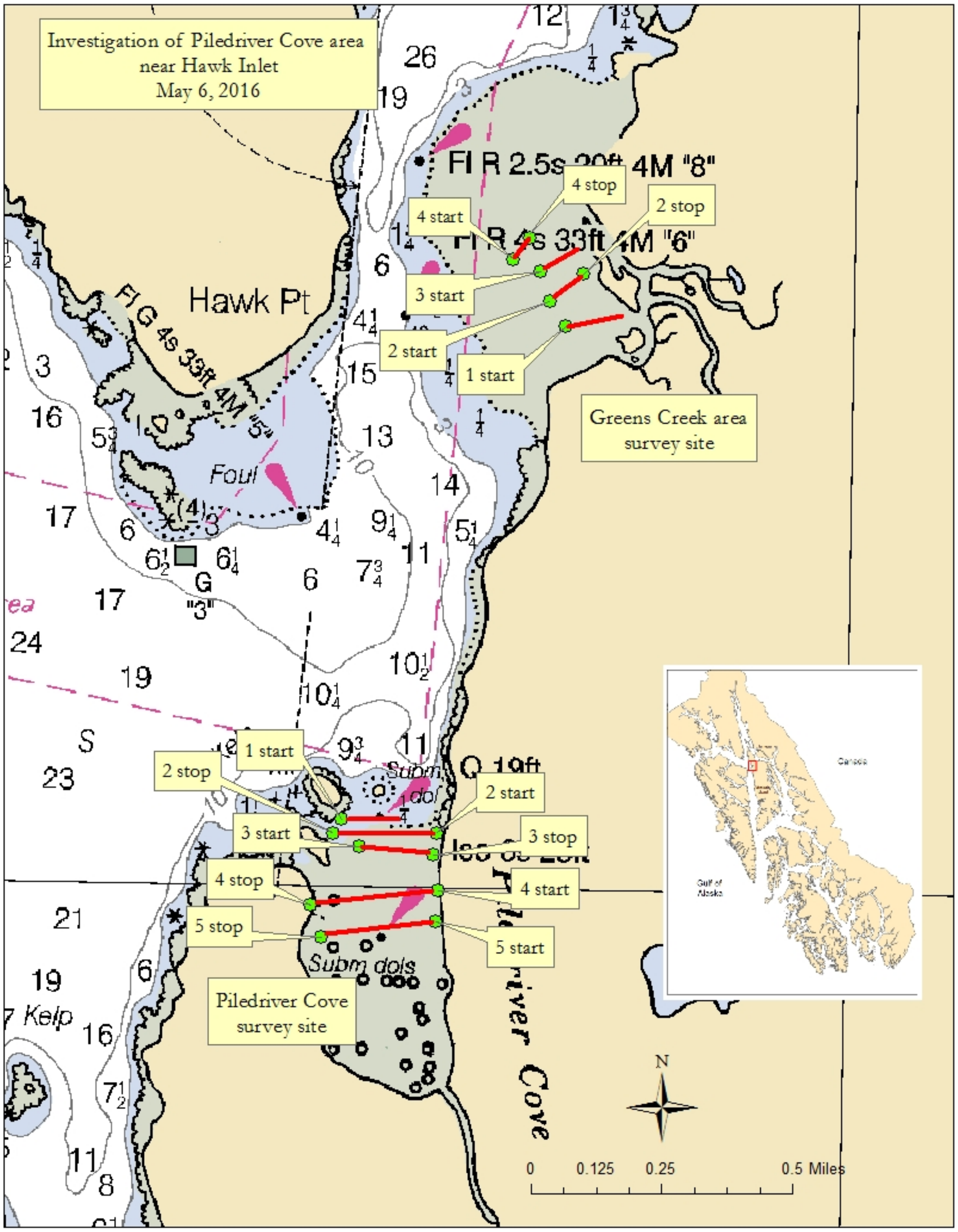


Figure 1.–Map of study sites with transect locations near the entrance of Hawk Inlet, Admiralty Island, Southeast Alaska.

CC:

Kate Kanouse, ADF&G Habitat, Douglas
Will Collingwood, ADEC Water, Juneau
Kyle Moselle, ADNR OPMP, Juneau
Matthew Reece, USFS, Juneau

HAWK INLET MONITORING PROGRAM
2007 ANNUAL REPORT

Kennecott Greens Creek Mining Company

January 2008

TABLE OF CONTENTS

TABLES (continued)

FIGURES (located at end of text)

FIGURES continued

1.0 INTRODUCTION

1.1 Site Description

The Kennecott Greens Creek Mine on Admiralty Island is located 18 miles southwest of the city of Juneau, Alaska. Dense forests cover the mountain slopes up to an elevation of 2500 feet, above which the vegetation is alpine. The climate is maritime, with precipitation similar to that in Juneau, averaging 60 to 70 inches per year at the mine site, and 45 to 55 inches per year at the facilities on Hawk Inlet. The mine and mill facilities (920 area) are located over 6 miles up Greens Creek from Hawk Inlet tidewater.

Zinc, lead, silver, and gold are the target recovery metals. The Kennecott Greens Creek Mining Company (KGCMC) operations began in August 1989, and operated approximately 4 years before production was suspended in April 1993. The mine and mill were recommissioned and operations restarted in mid-1996. A 2000 ton/day milling facility and appurtenant support facilities are in place at the 920 area. Filter pressed tailings from the milling process are backfilled in the mine and deposited in a surface dry-stack tailings pile near Hawk Inlet. Concentrate is transported from the mill to the Hawk Inlet area, where it is stored until it is shipped off-site.

Support facilities to the mining and milling operation at Hawk Inlet include core storage, concentrate storage and shipping, barge port facilities, and camp housing. A domestic waste water treatment plant and outfall are located at the Hawk Inlet port site.

Two waste water discharge outfalls, and 10 representative storm water discharge sites are authorized by the KGCMC National Pollutant Discharge Elimination System (NPDES) Permit Number AK-004320-6. Outfall 001 provides an emergency backup discharge point for the Hawk Inlet Camp domestic sewage and captured area runoff discharge located at the Hawk Inlet port facilities. Under normal operating conditions, the Hawk Inlet camp treated sewage is combined with area surface runoff, and pumped up to the Tailings Area. Here it is combined with effluent streams from the 920 and the Tailings Basin areas, treated and discharged through the submarine NPDES Outfall 002 onto the ocean floor in Hawk Inlet.

Hawk Inlet is a marine inlet formed during the late Holocene glaciation and is underlain by a series of late-Paleozoic to Mesozoic phyllitic-schist and greenstone formations. Hawk Inlet extends seven miles north from Chatham Strait to a tidal mudflat estuary about 0.6 miles in diameter. The narrow channel connecting the Inlet to Chatham Strait, located between the top of the Greens Creek delta and the western shore of Hawk Inlet, has a minimum low tide depth of 35 feet. The midchannel depth ranges from 35 feet to 250 feet. The Inlet has regular, twice-daily tides, with a maximum tidal variation of 25 feet. On the flood tide, the surface 35-foot layer contains the bulk of the water transport entering the Inlet and is then flushed out on the ebb tide. Flushing describes the rate and extent to which a body of water is replenished by tidal or other currents. Flushing rates are also indicative of the length of time that mining effluent may remain in a water body and become incorporated into the physical and biological ecosystem through ingestion, adsorption or other means. In 1981, dispersion dye testing in Hawk Inlet determined that over each tidal cycle, an average of 13 billion gallons of water is flushed from the Inlet (SEA Associates, 1981). At that rate, it is estimated that the Inlet will completely flush at least once every five tidal cycles. Based on the mine output up through 1995, the input of effluent from the mining operations over this flushing period represents approximately 0.009 percent of the total flushing volume (Ridgeway, 2003).

For more in-depth information on the physical and biological characteristics of Hawk Inlet, see *Technical Review of the Status of Essential Fish Habitat in Hawk Inlet Subsequent to Mining Operations*, Ridgeway, October 2003.

1.2 Hawk Inlet Monitoring Program

In anticipation of the Greens Creek Mine development, government agencies, scientists and biological consultants carried out surveys of marine life and baseline studies of heavy metals in the environment beginning in the early 1980s. Several researchers have studied marine life in Hawk Inlet, and the on-going quarterly and semi-annual monitoring events have generated an extensive time-series data set of coincident metal levels in water, sediment, and marine tissue samples.

This *Hawk Inlet Monitoring Program 2007 Annual Report* has been prepared by Kennecott Greens Creek Mining Company (KGCMC) in accordance with Section I.D.5 of the National Pollutant Discharge Elimination System (NPDES) Permit AK-004320-6. Reporting the Hawk Inlet monitoring program data in an annual report is a requirement of the renewed permit, which became effective July 1, 2005. Prior to this, the data were reported to EPA and ADEC in quarterly seawater reports.

The primary objective of the Hawk Inlet monitoring program is to document the water quality, sediment and biological conditions in receiving waters and marine environments that may be impacted by the mine’s operations. Sea water is sampled quarterly at three locations in Hawk Inlet, and sediment and invertebrate samples are taken each year in the spring and in the fall at four and seven locations, respectively. Figure 1-1 shows a site map with the sampling locations. Table 1-1 summarizes the requirements of the permit for sample parameters, sample preservation and holding time, sampling frequency, analytical methods and method required detection limits (MDLs). Specific quality assurance/quality control (QA/QC) requirements (i.e., sampling procedures, documentation, chain of custody processes, calibration procedures and frequency, data validation, corrective actions, etc.) are outlined in the NPDES Quality Assurance Project Plan: Project Monitoring Manual (KGCMC, 2005).

TABLE 1-1 Summary of NPDES Permit Sampling Requirements

NPDES Requirement	Parameter	Required Sampling Frequency	Sample Type	Sample Container	Sample Preservation	Laboratory	Holding Time	Analytical Method(s)	Minimum Required Method Detection Limit	Units	Comments
RECEIVING WATER COLUMN MONITORING											
I.D.1 Table 4	Dissolved Cadmium	Quarterly	Grab (1 sample for all metals)	1 ea. 500 ml Teflon bottle, yellow label (1 bottle for all metals)	HNO_3 to pH <2 by lab	Battelle Marine Sciences	6 months	EPA 213.2/ 1638	0.10	µg/L	MDLs set by NPDES permit Section I.D.1, Table 4
I.D.1 Table 4	Dissolved Copper	Quarterly						EPA 220.2/ 1638	0.03	µg/L	
I.D.1 Table 4	Dissolved Lead	Quarterly						EPA 239.2/ 1638	0.05	µg/L	
I.D.1 Table 4	Total Mercury	Quarterly					28 days	EPA 245.1/ 1631	0.20	µg/L	
I.D.1 Table 4	Dissolved Zinc	Quarterly					6 months	EPA 289.2/ 1638	0.20	µg/L	
I.D.1 Table 4	Total Suspended Solids	Quarterly	Grab	1 ea. 1 liter plastic bottle, white label	Cool to 4°C	Analytica Alaska	7 days	EPA 160.2/ SM 2540D	--	mg/L	
I.D.1 Table 4	Turbidity	Quarterly	Grab	1 ea. 1 liter plastic bottle	Cool to 4°C	Analytica Alaska	48 hours	EPA 180.1	--	NTU	
I.D.1 Table 4	WAD Cyanide	Quarterly	Grab	1 ea 1 liter plastic bottle, green label	NaOH to pH >12, cool to 4°C	Analytica Alaska	14 days	EPA 335.2/ SM 4500-CN-E	1.00	µg/L	Add 0.6g ascorbic acid, if chlorine is present.
I.D.1 Table 4	pH	Quarterly	Grab	NA	NA	Field measurement	15 min	EPA 150.1/ SM 4500-H, B	--	SU	
I.D.1 Table 4	Conductivity	Quarterly	Grab	NA	NA	Field measurement	20 days	EPA 120.1	--	µmhos/cm	
I.D.1 Table 4	Temperature	Quarterly	Grab	NA	NA	Field measurement	15 min	NA	--	°C	
BIOACCUMULATION WATER SEDIMENT MONITORING											
I.D.2 Table 5	Total Cadmium	Semi-annual	Grab	2 ea. 8 oz. plastic or glass jar	Freeze sample	Columbia Analytical Services (CAS)		PSEP/GFAA	0.30	mg/Kg	MDLs set by NPDES permit Section I.D.2, Table 5
I.D.2 Table 5	Total Copper	Semi-annual	Grab			CAS		PSEP/ICP	15.00	mg/Kg	
I.D.2 Table 5	Total Lead	Semi-annual	Grab			CAS		PSEP/ICP	0.50	mg/Kg	NMFS request dupilicate sampling since Fall 2004
I.D.2 Table 5	Total Mercury	Semi-annual	Grab			CAS		PSEP/ EPA 7471A	0.02	mg/Kg	
I.D.2 Table 5	Total Zinc	Semi-annual	Grab			CAS		PSEP/ICP	15.00	mg/Kg	
BIOACCUMULATION WATER IN-SITU BIOASSAY MONITORING											
I.D.3 Table 6	Total Cadmium	Semi-annual	Grab	2 ea. 8 oz. plastic or glass jar	Freeze sample	CAS		EPA 200.8/ 6020	not specified	mg/Kg	NMFS request dupilicate sampling since Fall 2004
I.D.3 Table 6	Total Copper	Semi-annual	Grab			CAS		EPA 200.8/ 6020	not specified	mg/Kg	
I.D.3 Table 6	Total Lead	Semi-annual	Grab			CAS		EPA 200.8/ 6020	not specified	mg/Kg	
I.D.3 Table 6	Total Mercury	Semi-annual	Grab			CAS		EPA 7471A	not specified	mg/Kg	
I.D.3 Table 6	Total Zinc	Semi-annual	Grab			CAS		EPA 200.8/ 6020	not specified	mg/Kg	

This report presents information on each of the three media sampled in Hawk Inlet: water column, sediments and in-situ bioassays. All results for the samples collected in 2007 are presented, along with the associated QA/QC data. Statistical evaluation of the data showing averages, variations, and changes over time are also included. The next section describes any deviations from the monitoring program that occurred in 2007, and the reasons for the deviations.

1.3 Deviation(s) from Monitoring Program and Incidents in 2007

Deviations from the monitoring program that occurred in 2007 are noted below:

- There were no deviations from the monitoring program in 2007.

The reissued NPDES Permit AK-004320-6 for Greens Creek became effective July 1, 2005. New or modified requirements of the reissued permit are described in detail in the *Hawk Inlet Monitoring Program 2005 Annual Report*.

Incidents that occurred in Hawk Inlet in 2007 are noted below, along with corrective and preventive actions:

- On May 10th, 2007, an estimated 10 pounds of zinc concentrate spilled into Hawk Inlet during ship loading operations due to a wire connector failure. The failed components were immediately fixed or replaced. Also, the personnel from Marine Taxonomic Services, LTD were instructed during their dives in the shiploader area during the spring and fall sampling events of 2007 to inspect the area to determine if any impacts were visible. Their inspections determined that there was no visible change in the underwater area near the shiploader after the spill. The June 2007 sediment sample at site 5S showed elevated zinc (3570 mg/kg versus the September 2006 result of 1720 mg/kg); however, the zinc concentration decreased in the August 2007 sediment sample to 330 mg/kg. None of the other two sediment sampling locations in the area, nor the tissue samples in the area in 2007 showed increased zinc concentrations after the spill. It is therefore difficult to say whether the elevated June 2007 zinc sediment sample result at 5S can be directly correlated to the May 2007 spill, or whether it was due to the previously documented fluctuations of metal concentrations in this area due to the incident in 1989 (see Section 3.2 of this report for more details). This area will continue to be monitored on a semi-annual basis.

2.0 WATER COLUMN MONITORING

The receiving water column monitoring requirements originate from Section I.D.1 and Table 4 of the NPDES permit. The objective of the receiving water column monitoring element of the sampling program is to provide scientifically valid data on specific physical and chemical parameters for Hawk Inlet water quality. These data are used to evaluate potential changes in the Hawk Inlet marine environment.

Three ocean sites in Hawk Inlet are sampled to monitor potential water quality effects from the mine. Seawater samples are collected quarterly from the sites on an outgoing tide, with the Chatham Strait sample (Site 106) collected just after low slack water. The two other sites are Station 107, located about mid-way East-West in Hawk Inlet and west of the ship loader facility, and Station 108, located above the 002 diffuser in the mixing zone. Samples at all three locations are taken at a depth of five feet.

Water samples are sent to Battelle Marine Science Lab in Sequim, Washington, for low level dissolved trace metals analyses, and to Analytica Alaska - SE in Juneau, Alaska for pH, conductivity, WAD cyanide, total suspended solids, and turbidity analyses. Analytica subcontracts with Frontier Geosciences in Washington for the analyses of WAD cyanide in order to obtain the required MDL. Temperature, pH, turbidity and conductivity are measured in the field by the Environmental staff. The majority of the field conductivity readings were not corrected for temperature.

2.1 2007 Analytical Results

The tables in this section summarize the results for the quarterly water column monitoring conducted in 2007.

TABLE 2-1 Hawk Inlet Field Parameters 2007 (sample depth 5’)

	Sample Date	Sample Time	Weather Conditions	Conductivity (µmhos/cm)	pH	Temp. (°C)
Site 106						
	3/13/07	15:18	Breezy, cold	38,940	7.97	3.1
	6/20/07	12:01	cloudy, breezy	30,730	8.31	9.0
	8/15/07	09:37	Clear, calm, warm	30,280	8.39	11.8
	10/17/07	10:51	Partly cloudy, breezy	29,250	7.96	7.9
Site 107						
	3/13/07	14:40	Breezy, cold	38,900	7.92	2.5
	6/20/07	11:05	cloudy, calm	33,940	8.52	9.8
	8/15/07	08:43	Clear, calm, warm	34,270	8.13	11.1
	10/17/07	10:08	Partly cloudy, breezy	32,240	7.99	8.0
Site 108						
	3/13/07	15:01	Cold, windy	38,840	7.97	2.6
	6/20/07	11:34	cloudy	31,010	8.31	9.2
	8/15/07	09:05	Clear, 0-5 S wind, warm	32,210	8.11	11.3
	10/17/07	10:31	Partly cloudy	29,780	7.97	7.6

TABLE 2-2 Hawk Inlet Water Column Monitoring 2007: Nonmetal Parameters

(Analytica Alaska Laboratory) (sample depth 5’)

	Sample Date	TSS (mg/L)	Turbidity (NTU)	WAD CN* (µg/L)	pH (su)	Conductivity (µmhos/cm)
Site 106						
	3/13/07	21.0	0.56	<1.00	7.73	44,800
	6/20/07	19.0	0.48	1.30	8.16	41,200
	8/15/07	19.0	0.38	1.40	8.16	35,500
	10/17/07	48.0	0.24	<1.00	7.81	40,300
Site 107						
	3/13/07	18.0	1.1	<1.00	7.74	44,800
	6/20/07	30.0	0.97	1.10	8.08	40,000
	8/15/07	4.00	0.69	1.40	8.12	39,600
	10/17/07	49.0	0.52	<1.00	7.84	40,000
Site 108						
	3/13/07	20.0	0.64	<1.00	7.75	45,100
	6/20/07	19.0	1.1	1.30	8.04	40,300
	8/15/07	21.0	0.74	1.40	8.10	39,500
	10/17/07	36.0	0.56	<1.00	7.82	39,300

*analyzed by Frontier Geosciences to achieve required MDL=1.00 µg/L

TABLE 2-3 Hawk Inlet Water Column Monitoring Results 2007: Metals
(Battelle Marine Sciences Laboratory) (sample depth 5')

	Sample Date	Cd (µg/L) Dissolved	Cu (µg/L) Dissolved	Pb (µg/L) Dissolved	Hg (µg/L) Total	Zn (µg/L) Dissolved
Lab MDL		*(0.005)*	*(0.025)*	*(0.003)*	*(0.00012)*	*(0.162 0.042)*
Req. MDL		*(0.10)*	*(0.03)*	*(0.05)*	*(0.0002)*	*(0.20)*
Site 106						
	3/13/07	0.0680	0.391	0.0660	0.00063	0.640
	6/20/07	0.0652	0.332	0.171	0.000951	0.785
	8/15/07	0.0635	0.354	0.240	0.000555	2.92
	10/17/07	0.0752	0.451	0.0697	0.000537	1.25
Site 107						
	3/13/07	0.0738	0.416	0.0676	0.000608	1.15
	6/20/07	0.0683	0.697	0.110	0.000939	1.85
	8/15/07	0.0494	0.312	0.0679	0.00796	0.551
	10/17/07	0.0736	0.552	0.298	0.000732	1.08
Site 108						
	3/13/07	0.0716	0.363	0.0612	0.000612	1.16
	6/20/07	0.0657	0.379	0.0605	0.000800	0.914
	8/15/07	0.0555	0.309	0.0729	0.000381	0.727
	10/17/07	0.0611	0.485	0.319	0.00818	2.94

2.2 Data Evaluation

Figures 2-1a, b, c through 2-7a, b, c show the time series plots of pH, conductivity, cadmium, copper, lead, mercury and zinc for Stations 106 (2-1a through 2-7a), 107 (2-1b through 2-7b) and 108 (2-1c through 2-7c). The Alaska Water Quality Standards (AWQS) for marine aquatic life – chronic levels, are shown or noted on the graphs where applicable. The graphs show that the KGCMC results remain within or below these standards in all historical and 2007 samples.

The variability in conductivity values in 2002 at all three sites (Figures 2-2a, b, c) can be attributed to changes in field instruments during this timeframe.

Table 2-4 summarizes the past two year's average metals values for the sea water samples, compared to the current year's results. Due to the analytical change from total recoverable metals to dissolved metals requirements on these water samples with the reissued permit, there were only two dissolved metal data points in 2005.

TABLE 2-4 Hawk Inlet Water Column Average Dissolved Metal Concentrations

	Cd (µg/L)		**Cu** (µg/L)		**Pb** (µg/L)		**Hg** (TOTAL - µg/L)		**Zn** (µg/L)	
	05&06	**2007**	**05&06**	**2007**	**05&06**	**2007**	**05&06**	**2007**	**05&06**	**2007**
Site 106	0.0623	0.0680	0.399	0.382	0.156	0.137	0.00089	0.00067	0.730	1.399
Site 107	0.0722	0.0663	0.444	0.494	0.277	0.136	0.00092	0.00256	1.172	1.158
Site 108	0.0669	0.0635	0.437	0.384	0.145	0.128	0.00084	0.00249	0.694	1.435

2.3 QA/QC Results

Battelle Marine Science, Analytica Alaska and Frontier Geosciences Laboratories analyzed the required parameters (see Table 1-1) in the sea water samples. Complete QA plans and reports are kept on file in each lab's office and are available upon request. The remainder of this section summarizes the relevant QA/QC results from each laboratory for the 2007 sea water samples (taken quarterly – 1Q07, 2Q07, 3Q07, and 4Q07).

Analytica Alaska (WAD cyanide, total suspended solids (TSS), pH, conductivity, and turbidity analyses)
1Q07, 2Q07, 3Q07, 4Q07: All method specifications were met, except for turbidity measured above the laboratory PQL (0.125 measured; 0.1 PQL) in the method blank of DI water in 4Q07.

1Q07, 2Q07, 3Q07, 4Q07: Frontier Geosciences (subcontracted through Analytica for WAD CN): All QC results were within predetermined data quality control limits.

Battelle Marine Science (low level dissolved trace metals analyses in salt water matrices)
1Q07: Target detection limits were met. Matrix spike and duplicates of standard reference materials (SRM) were within data quality objective of ±25%. Method blank results were less than the MDL for zinc and cadmium, but greater than the MDL for copper and mercury. Detected levels in the blank were less than 10 times the MDL.

2Q07: Target detection limits were met. Method blank results were less than the MDL for zinc, cadmium, and mercury, but greater than the detection limit for copper and lead. Matrix spike and duplicates of SRM were within ±25%.

3Q07: Target detection limits were met, except copper, where the MDL was 0.048 relative to the target detection limit of 0.03. Method blank results were less than the MDL for zinc, cadmium and mercury, but greater than the MDL for copper and lead. Detected levels in the blanks were less than ten times the MDL. Matrix spike and duplicates of SRM were within ±25%, except lead in the SRM where the certified value is near the MDL, and the duplicate for lead.

4Q07: Target detection limits were met for all metals, except copper where the MDL is 0.048 relative to the target detection limit of 0.03. Method blank results were less than the MDL for zinc, cadmium and mercury, but greater than the detection limit for copper and lead. Detected levels in the blank were less than ten times the MDL. Standard reference material (SRM), matrix spike and duplicate results were within the default criteria of ±25%.

3.0 SEDIMENT MONITORING

The requirements for the sediment monitoring originate from Section I.D.2, Sediment Monitoring, and Table 5 of the NPDES permit. The objective of this element of the monitoring program is to provide scientifically valid data on five specific trace metal parameters from sediments at four locations in Hawk Inlet. These data are used to evaluate potential changes in the Hawk Inlet marine environment.

The sediment samples are collected semi-annually in the spring and fall at the Greens Creek delta (Site S-1), Pile Driver Cove near the mouth of the inlet (Site S-2), near the ore dock (Site S-4), and under the ship's berth near the old cannery (Site S-5N and S-5S which bracket the area where concentrate was spilled in 1989). The samples are analyzed at Columbia Analytical Services, Inc. in Kelso, Washington for total concentrations of five trace metals (Cd, Cu, Pb, Hg, and Zn).

An additional location, Site S-3, has also been sampled for sediments since the 1980s. Site S-3 is located at the head of Hawk Inlet. Data collected from Site S-3 exhibited different trends from the other two background stations (S-1 and S-2). Most metals at S-3 were found at higher levels than at S-1 or S-2. Field observations of a mass wasting event in the watershed above S-3 appears to have released metals from abandoned historic mine workings (Alaska Rand Group) into the environment (Ridgeway, 2003). For this reason, when the reissued permit became effective July 1, 2005, S-3 was dropped from the list of active sediment sampling sites. Therefore, data from S-3 are not presented in this report.

3.1 2007 Analytical Results

All sediment samples were collected by Marine Taxonomic Services, LTD. The sample locations, dates, times, weather conditions, and tides are shown in Table 3-1. Tables 3-2 and 3-3 in this section summarize the total metals results for the semi-annual sediment monitoring events. Sample labels I, II, and III denote duplicate samples taken at each sample site.

TABLE 3-1 Hawk Inlet Sediment Monitoring Field Parameters 2007

Locations	Date Sampled	Time Sampled	Weather Conditions	Tide Ht.
S-1	6/14/07	07:15	Partly cloudy, nice day	-3.8
	8/29/07	07:20	overcast	-2.0
S-2	6/14/07	08:00	Partly cloudy, nice day	-3.8
	8/30/07	07:30	overcast	1.1
S-4	6/17/07	09:15	Cloudy	-3.2
	8/31/07	09:30	Rain-heavy, overcast	1.3
S-5S	6/15/07	13:30	Partly cloudy	12.2
	8/29/07	14:30	overcast	17.2
S-5N	6/15/07	13:45	Partly cloudy	12.3
	8/29/07	14:30	overcast	17.2

TABLE 3-2 Hawk Inlet Sediment Results for Spring 2007
(Columbia Analytical Services Laboratory)

Sample No.	**Sample date**	**Cd** **(mg/kg dw)**	**Cu** **(mg/kg dw)**	**Pb** **(mg/kg dw)**	**Hg** **(mg/kg dw)**	**Zn** **(mg/kg dw)**
Lab MRL		*(0.05)*	*(0.1)*	*(0.05)*	*(0.02)*	*(0.5)*
Required MDL		*(0.3)*	*(15.0)*	*(0.05)*	*(0.02)*	*(15.0)*
S-1 Sediments-Metals I	6/14/07	0.17	12.9	6.76	0.02	89.2
S-1 Sediments-Metals II	6/14/07	0.17	13.7	6.77	0.03	86.2
S-1 Sediments-Metals III	6/14/07	0.15	15.1	6.33	0.03	82.3
S-2 Sediments-Metals I	6/14/07	0.20	8.7	1.76	<0.02	29.8
S-2 Sediments-Metals II	6/14/07	0.13	10.0	1.84	<0.02	38.8
S-2 Sediments-Metals III	6/14/07	0.19	10.0	2.01	<0.02	39.9
S-4 Sediments-Metals I	6/14/07	0.26	27.4	17.6	0.03	51.0
S-4 Sediments-Metals II	6/14/07	0.24	14.6	18.4	0.02	66.9
S-4 Sediments-Metals III	6/14/07	0.29	72.5	21.9	0.03	53.2
S-5N Sediments-Metals I	6/14/07	2.30	66.9	239	0.20	971
S-5N Sediments-Metals II	6/14/07	1.56	36.2	189	0.39	310
S-5N Sediments-Metals III	6/14/07	1.80	41.1	160	0.15	382
S-5S Sediments-Metals I	6/14/07	17.2	119	555	1.0	3570
S-5S Sediments-Metals II	6/14/07	17.8	148	513	0.99	3770
S-5S Sediments-Metals III	6/14/07	14.8	103	437	0.83	3000

TABLE 3-3 Hawk Inlet Sediment Results for Fall 2007
(Columbia Analytical Services Laboratory)

Sample No.	**Sample date**	**Cd** **(mg/kg dw)**	**Cu** **(mg/kg dw)**	**Pb** **(mg/kg dw)**	**Hg** **(mg/kg dw)**	**Zn** **(mg/kg dw)**
Lab MRL		*(0.05)*	*(0.1)*	*(0.05)*	*(0.01)*	*(0.5)*
Required MDL		*(0.3)*	*(15.0)*	*(0.05)*	*(0.02)*	*(15.0)*
S-1 Sediments-Metals I	8/29/07	0.09	12.3	5.42	0.04	80.0
S-1 Sediments-Metals II	8/29/07	0.15	14.5	6.06	0.04	106
S-1 Sediments-Metals III	8/29/07	0.16	22.5	7.92	0.08	114
S-2 Sediments-Metals I	8/29/07	0.15	9.5	1.91	0.02	43.1
S-2 Sediments-Metals II	8/29/07	0.14	8.6	1.79	<0.02	44.0
S-2 Sediments-Metals III	8/29/07	0.15	9.1	1.97	<0.02	39.9
S-4 Sediments-Metals I	8/29/07	0.29	21.7	116	0.04	68.3
S-4 Sediments-Metals II	8/29/07	0.36	21.3	59.4	0.04	75.4
S-4 Sediments-Metals III	8/29/07	0.56	20.4	31.6	0.04	239
S-5N Sediments-Metals I	8/29/07	0.26	625	42.9	0.07	473
S-5N Sediments-Metals II	8/29/07	0.41	89.0	53.3	0.07	150
S-5N Sediments-Metals III	8/29/07	0.26	42.5	47.6	0.06	115
S-5S Sediments-Metals I	8/29/07	1.61	57.9	223	0.52	330
S-5S Sediments-Metals II	8/29/07	0.97	367	91.1	0.21	315
S-5S Sediments-Metals III	8/29/07	1.46	39.2	90.8	0.18	543

3.2 Data Evaluation

Prior to opening the Greens Creek mine for full production in August 1989, sediment and biota tissues were sampled for heavy metal concentrations. Sampling sites S-1 and S-2 were chosen to represent natural conditions; therefore, results from these sites from June of 1984 until August of 1989 were used to calculate baseline, pre-production values. These data are useful as baseline values against which to compare metal values after mining began (Table 3-4), and the results for the current year's sampling. Sampling sites S-4 and S-5 are thought to have been influenced by the old cannery operation and mine exploration work and are not suitable for background calculations.

TABLE 3-4 Hawk Inlet Sediment Data: Pre-Production Baseline, Production Period and Current Year Comparison

Metal	Pre-Production (6/1984-8/1989)			Production (9/1989-9/2006)			Current Year 2007		
	Avg	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**
Cd	0.245	0.03	0.87	0.216	0.06	0.89	0.152	0.09	0.2
Cu	18.75	11.9	33	15.5	7.5	39.5	10.85	8.7	12.9
Pb	6.72	2.2	13	6.07	1.48	23.7	3.96	1.76	12.9
Hg	0.035	0.002	0.094	0.02	0.02	0.14	0.02	0.02	0.04
Zn	96.0	52.8	155	76.8	26.1	185	60.5	29.8	89.2

NOTE: Data are compilation of results from Stations S-1 and S-2; underlined/bolded values higher than baseline

The comparison of pre-production and production sediment metal values in Table 3-4 shows that across Stations S-1 and S-2, the average metal levels are lower during the production/mining period than they were during pre-production. The current year's results show the average metals levels to be below the production period's average values for all metals. In 2006, all of the average metals concentrations were greater than the average production values (KGCMC, 2007). Based on these data, it appears that heavy metals in sediment near the outfall 002 site continue to vary from year to year, and have not increased above the range of area-wide baseline levels during mining years.

Figures 3-1 through 3-5 show the time series plots for cadmium, copper, lead, mercury and zinc for sampling sites S-1 and S-2. Linear regression analyses on the production era data plots indicate that all five metal's concentration have not increased with time.

Sampling sites S-4 and S-5S and S-5N are located near the ore concentrate loading facility. In 1989, the first attempt to load a barge with ore concentrate resulted in a spill of concentrate into Hawk Inlet. A suction dredge company was brought on-site in 1995 to dredge the available concentrate off of the ocean floor. This effort was confounded somewhat by the residual debris from the 1974 cannery facility fire. Although clean-up efforts were extensive, liter-sized pockets of concentrate are still observed throughout the area. Prop wash from ore ships and associated tug boats continues to both re-suspend these pockets and also mix them with natural sediments.

After the 1995 clean-up, the sampling methodology at S-5 was expanded. The site was sub-divided into two separate locations: adding site S-5S located on the south side of the spill area, to complement S-5N located on the north side. Following the spill, metal concentrations in the sediment in this area have been elevated and variable. Figures 3-6 through 3-10 show the metal time series graphs for these three sites. Linear regression analyses on the production era data for S-4 indicate that the concentration of all five metals is not increasing with time.

Table 3-5 shows the average metal concentrations and the associated standard deviations for each sediment sampling site during pre-production and production. Production data do not including the current year’s results. Pre-production sediment metals average levels show some consistency across stations, but the standard deviations for these data indicate high variability, representative of typical natural distributions.

TABLE 3-5 Average and Standard Deviation Values for Pre-Production and Production Sediment Data

Metal (mg/kg dw)	S-1				S-2			
	pre-production (9/1984-8/1989)		production (9/1989 - 9/2006)		pre-production (9/1984-8/1989)		production (9/1989 - 9/2006)	
	avg	stdev	avg	stdev	avg	stdev	avg	stdev
Cd	0.253	0.222	**0.261**	0.196	0.236	0.119	0.171	0.086
Cu	22.5	5.19	18.5	7.73	15.01	2.68	12.52	4.35
Pb	8.175	2.628	**9.17**	4.86	5.26	2.161	2.97	1.92
Hg	0.0441	0.0209	0.032	0.037	0.0253	0.015	0.009	0.022
Zn	129.2	11.55	105.7	33.03	62.93	6.68	47.9	14.44

Metal (mg/kg dw)	S-4				S-5N		S-5S	
	pre-production (9/1984-8/1989)		production (9/1989 - 9/2006)		post spill (9/1989 - 9/2006)		post spill (6/1995 - 9/2006)	
	avg	stdev	avg	stdev	avg	stdev	avg	stdev
Cd	0.761	1.097	**1.035**	0.95	15.04	44.52	3.76	4.22
Cu	49.04	19.25	**60.18**	60.1	253.3	416.6	82.8	43.7
Pb	108.2	136.8	**133.0**	146.3	1187.9	2601.3	261.5	219.1
Hg	0.115	0.083	**0.206**	0.629	2.36	6.176	0.395	0.333
Zn	179.2	125.5	**212.6**	197.49	2345.2	6078.4	793.6	852.7

NOTE: Underlined/bolded averages are higher than pre-production averages

3.3 QA/QC Results

Columbia Analytical Laboratory analyzed the required parameters (see Table 1-1) in the sediment samples. Complete QA plans and reports are kept on file in the lab’s office and are available upon request. The remainder of this section summarizes the relevant QA/QC results for the spring and fall sampling events in 2007.

Spring 2007:
The control criteria for matrix spike recoveries of lead and zinc for samples S-5N Sediment-Metals I and S-5S Sediment-Metals I are not applicable. The analyte concentrations in the samples were significantly higher than the spike concentrations, preventing accurate evaluations of spike recoveries.

The matrix spike recovery of copper for sample S-5N Sediment-Metals I was outside of the lab's control criteria as a result of the heterogeneity of the sample. The Relative Percent Difference (RPD) for the replicate analysis supports this. Since the unspiked samples contain high analyte concentrations relative to the amount spiked, the variability between replicates was sufficient to bias the percent recoveries outside normal lab control criteria. The associated QA/QC results (i.e., control sample, calibration standards, etc.) indicate the analysis was in control. No further corrective action was appropriate.

The relative percent difference for the replicate analysis of zinc in sample S-5N Sediment-Metals I was outside the normal lab control limits. The variability in the results is attributed to the heterogeneous character of the sample. Standard mixing techniques were used, but were not sufficient for complete homogenization of this sample.

Fall 2007:
The matrix spike recovery of lead for sample S-4 Sediment-Metals II was outside of the lab's control criteria as a result of the heterogeneity of the sample. The Relative Percent Difference (RPD) for the replicate analysis supports this. Since the unspiked samples contain high analyte concentrations relative to the amount spiked, the variability between replicates was sufficient to bias the percent recoveries outside normal lab control criteria. The associated QA/QC results (i.e., control sample, calibration standards, etc.) indicate the analysis was in control. No further corrective action was appropriate.

The RPD for the replicate analysis of lead in sample S-4 Sediment-Metals II was outside the normal lab control limits. The variability in the results is attributed to the heterogeneous character of the sample. Standard mixing techniques were used, but were not sufficient for complete homogenization of this sample.

Beginning in the fall of 2004, duplicate samples have been collected from each site, where possible, to address a National Marine Fisheries Service request. Precision can be calculated from the results of duplicate samples. In this case, the relative standard deviation RSD (the standard deviation relative to the mean, expressed as a percent) is shown for the duplicate samples from 2007 in Table 3-6.

TABLE 3-6 RSDs for Duplicate Sediment Samples

SAMPLE ID	DATE	Cd	Cu	Pb	Hg	Zn
		(mg/kg dw)	(mg/kg dw)	(mg/kg dw)	(mg/kg dw)	(mg/kg dw)
	DL	0.05	0.1	0.05	0.02	0.5
S-1 Sediments-Metals I	6/14/07	0.17	12.9	6.76	0.02	89.2
S-1 Sediments-Metals II	6/14/07	0.17	13.7	6.77	0.03	86.2
S-1 Sediments-Metals III	6/14/07	0.15	15.1	6.33	0.03	82.3
RSD		***7.07***	***8.01***	***3.79***	**--**	***4.03***
S-2 Sediments-Metals I	6/14/07	0.2	8.7	1.76	<0.02	29.8
S-2 Sediments-Metals II	6/14/07	0.13	10	1.84	<0.02	38.8
S-2 Sediments-Metals III	6/14/07	0.19	10	2.01	<0.02	39.9
RSD		**--**	***7.85***	***6.83***	**--**	***15.32***
S-4 Sediments-Metals I	6/14/07	0.26	27.4	17.6	0.03	51
S-4 Sediments-Metals II	6/14/07	0.24	14.6	18.4	0.02	66.9
S-4 Sediments-Metals III	6/14/07	0.29	72.5	21.9	0.03	53.2
RSD		***9.56***	***79.7***	***11.85***	**--**	***15.11***
S-5N Sediments-Metals I	6/14/07	2.3	66.9	239	0.2	971
S-5N Sediments-Metals II	6/14/07	1.56	36.2	189	0.39	310
S-5N Sediments-Metals III	6/14/07	1.8	41.1	160	0.15	382
RSD		***20.0***	***34.3***	***20.4***	***51.3***	***65.2***
S-5S Sediments-Metals I	6/14/07	17.2	119	555	1	3570
S-5S Sediments-Metals II	6/14/07	17.8	148	513	0.99	3770
S-5S Sediments-Metals III	6/14/07	14.8	103	437	0.83	3000
RSD		***9.56***	***18.5***	***11.9***	**--**	***11.6***

TABLE 3-6 RSDs for Duplicate Sediment Samples (continued)

SAMPLE ID	DATE	Cd	Cu	Pb	Hg	Zn
S-1 Sediments-Metals I	8/29/07	0.09	12.3	5.42	0.04	80
S-1 Sediments-Metals II	8/29/07	0.15	14.5	6.06	0.04	106
S-1 Sediments-Metals III	8/29/07	0.16	22.5	7.92	0.08	114
RSD		**--**	***32.7***	***20.1***	**--**	***17.8***
S-2 Sediments-Metals I	8/29/07	0.15	9.5	1.91	0.02	43.1
S-2 Sediments-Metals II	8/29/07	0.14	8.6	1.79	<0.02	44
S-2 Sediments-Metals III	8/29/07	0.15	9.1	1.97	<0.02	39.9
RSD		**--**	***4.97***	***4.85***	**--**	***5.09***
S-4 Sediments-Metals I	8/29/07	0.29	21.7	116	0.04	68.3
S-4 Sediments-Metals II	8/29/07	0.36	21.3	59.4	0.04	75.4
S-4 Sediments-Metals III	8/29/07	0.56	20.4	31.6	0.04	239
RSD		***34.7***	***3.15***	***62.3***	**--**	***75.7***
S-5N Sediments-Metals I	8/29/07	0.26	625	42.9	0.07	473
S-5N Sediments-Metals II	8/29/07	0.41	89	53.3	0.07	150
S-5N Sediments-Metals III	8/29/07	0.26	42.5	47.6	0.06	115
RSD		***27.9***	***128.4***	***10.87***	**--**	***80.2***
S-5S Sediments-Metals I	8/29/07	1.61	57.9	223	0.52	330
S-5S Sediments-Metals II	8/29/07	0.97	367	91.1	0.21	315
S-5S Sediments-Metals III	8/29/07	1.46	93.2	90.8	0.18	534
RSD		***24.8***	***97.9***	***56.4***	***62.1***	***31.1***

-- indicates RSD was not calculated because one or more of the values was less than 4 times the DL

The data quality objectives for the RSD are less than or equal to 30 percent, when the values are at least four times the detection limit. Fourteen out of the 39 (approximately 36 percent) RSDs calculated for the 2007 duplicate samples were not within this data quality objective. Thirteen of the fourteen samples that were out of the required limits were from sample sites S-5S (4), S-5N (5), and S-4 (4), which are the sites that surround the area near the shiploader where a concentrate spill occurred in 1989. Due to the isolated pockets of concentrate remaining from the clean-up effort in 1995, sampling at these sites continues to show the greatest variability with associated higher RSDs typical of mixed population samples. The remaining sample that was over the data quality object of 30 percent was from S-1, where the copper samples’ RSD was 33 percent for the fall sampling event.

4.0 IN-SITU BIOASSAYS

The requirements for the bioassay monitoring originate from Section I.D.3, In-situ Bioassays, and Table 5 of the NPDES permit. The objective of this element of the monitoring program is to provide scientifically valid data on five specific trace metal parameters from the tissues of polychaete worms (*Nephtys*) and mussels at seven locations in Hawk Inlet. These data are used to evaluate potential changes in the Hawk Inlet marine environment.

Bioaccumulation in-situ bioassay sampling in Hawk Inlet consists of semi-annual testing of trace metal tissue burdens of selected species of invertebrate organisms with different feeding guilds. In the Hawk Inlet sill area, where no fine grained sediments occur, four sites (Stations STN-1, STN-2, STN-3 and East Shoal Light (ESL)) are used for in-situ bioassay monitoring of trace metals in bay mussels (*Mytilus edulis*). Data gathered from this area measures the response in organisms in the immediate vicinity of the process effluent discharge. In most other areas of Hawk Inlet, the bottom is covered with sediment. Consequently, samples of sediment dwelling polychaete worms (*Nephtys procera*), and when available sediment dwelling bivalves (*Cockles* and *Littleneck Clams*) are collected at three additional sites (S-1, S-2, and S-4).

An additional location, Site S-3, has also been sampled for biota since the 1980s. Site S-3 is located at the head of Hawk Inlet. Field observations of a mass wasting event in the watershed above S-3 appears to have released metals from abandoned historic mine workings (Alaska Rand Group) into the environment (Ridgeway, 2003). For this reason, when the reissued permit became effective July 1, 2005, S-3 was dropped from the list of active bioassay sampling sites. Therefore, data from S-3 are not presented in this report.

4.1 2007 Analytical Results

All tissue samples were collected by Marine Taxonomic Services, LTD. The sample locations, types, dates, times, weather conditions, and tides are shown in Table 4-1. Tables 4-2 and 4-3 in this section summarize the total metals results for the semi-annual bioassays. Sample labels I, II, and III denote duplicate samples taken at each site. Duplicate samples are not taken for all species due to the negative impact such removal would have on the relatively sparse populations present on the Hawk Inlet bioassay monitoring sample sites.

TABLE 4-1 Hawk Inlet Tissue Sampling Field Data 2007

Locations	Sample Type	Date Sampled	Time Sampled	Weather Conditions	Tide Ht.
S-1	Nephtys	6/14/07	07:15	Partly cloudy, nice day	-3.8
	Cockle	6/14/07	07:15	Partly cloudy, nice day	-3.8
	Nephtys	8/29/07	07:20	overcast	-2.0
	Cockle	8/29/07	07:20	overcast	-2.0
S-2	Nephtys	6/14/07	08:00	Partly cloudy, nice day	-2.0
	Cockle	6/14/07	08:00	Partly cloudy, nice day	-2.0
	Littleneck	6/14/07	08:00	Partly cloudy, nice day	-2.0
	Nephtys	8/30/07	08:10	overcast	1.1
	Cockle	8/30/07	08:10	overcast	1.1
	Abernicola	8/28/07	06:50	overcast	-2.0
S-4	Nephtys	6/17/07	09:15	Cloudy	-3.2
	Cockle	6/17/07	09:15	Cloudy	-3.2
	Nephtys	8/31/07	09:30	overcast	1.3
	Cockle	8/31/07	09:30	overcast	1.3
STN-1	Mussels	6/16/07	08:50	Cloudy, windy	-4.0
	Mussels	8/30/07	11:30	overcast	5.0
STN-2	Mussels	6/16/07	08:50	Cloudy, windy	-4.0
	Mussels	8/30/07	11:45	overcast	5.0
STN-3	Mussels	6/16/07	08:50	Cloudy, windy	-4.0
	Mussels	8/29/07	10:30	overcast	-0.4
ESL	Mussels	6/16/07	08:50	Cloudy, windy	-4.0
	Mussels	8/28/07	10:00	overcast	2.9

TABLE 4-2 Hawk Inlet Tissue Results for Spring 2007
(Columbia Analytical Services Laboratory)

Sample No.	Sample date	Cd (mg/kg dw)	Cu (mg/kg dw)	Pb (mg/kg dw)	Hg (mg/kg dw)	Zn (mg/kg dw)
BIOASSAYS						
Lab MRL		(0.02)	(0.1)	(0.02)	(0.02)	(0.5)
S-1 Nephtys I	6/14/07	3.36	12.9	0.81	0.05	250
S-1 Nephtys II	6/14/07	3.46	13.0	1.0	0.04	250
S-1 Nephtys III	6/14/07	3.10	10.9	0.86	0.05	235
S-1 Cockle Clams	6/14/07	1.03	8.9	1.98	0.03	118
S-2 Nephtys I	6/14/07	0.92	9.2	0.78	<0.02	181
S-2 Nephtys II	6/14/07	1.09	11	0.94	<0.02	195
S-2 Nephtys III	6/14/07	1.08	10.8	0.93	<0.02	185
S-2 Cockle Clams	6/14/07	0.91	8.7	0.71	<0.02	79.8
S-2 Little Neck Clams	6/14/07	2.67	7.7	0.29	<0.02	82.4
STN-1 Mussels	6/14/07	9.07	8.9	2.32	0.03	106
S-4 Nephtys I	6/14/07	0.60	9.8	7.01	<0.02	205
S-4 Nephtys II	6/14/07	0.40	11.6	5.81	<0.02	220
S-4 Nephtys III	6/14/07	0.75	13.7	6.36	<0.02	249
S-4 Cockle Clams	6/14/07	0.78	7.4	5.26	<0.02	84.0
STN-2 Mussels	6/14/07	8.60	7.2	126	0.03	104
STN-3 Mussels	6/14/07	9.43	9.2	2.46	0.03	99.2
ESL Mussels	6/14/07	6.54	10.6	2.89	0.02	94.0

TABLE 4-3 Hawk Inlet Tissue Results for Fall 2007
(Columbia Analytical Services Laboratory)

Sample No.	Sample date	Cd (mg/kg dw)	Cu (mg/kg dw)	Pb (mg/kg dw)	Hg (mg/kg dw)	Zn (mg/kg dw)
BIOASSAYS						
Lab MRL		(0.02)	(0.1)	(0.02)	(0.02; 0.03)	(0.5)
S-1 Nephtys I	8/29/07	3.79	22.0	0.62	<0.02	234
S-1 Nephtys II	8/29/07	3.15	13.0	0.71	0.08	285
S-1 Nephtys III	8/29/07	4.00	13.7	0.88	0.05	274
S-1 Cockle Clams	8/29/07	0.85	3.7	0.71	<0.02	64.3
S-2 Nephtys I	8/29/07	2.37	11.0	0.59	<0.02	199
S-2 Nephtys II	8/29/07	3.46	14.7	0.59	<0.02	261
S-2 Nephtys III	8/29/07	3.17	15.3	0.56	0.03	267
S-2 Cockle Clams	8/29/07	0.73	10.2	0.35	<0.02	79.6
S-2 Little Neck Clams	8/29/07	3.59	10.2	1.06	<0.02	111
S-4 Nephtys I	8/29/07	0.37	10.3	4.77	<0.02	207
S-4 Nephtys II	8/29/07	0.50	20.3	4.40	<0.02	191
S-4 Nephtys III	8/29/07	0.38	26.0	4.30	<0.02	166
S-4 Cockle Clams	8/29/07	0.59	43	4.45	<0.02	95.0
STN-1 Mussels	8/29/07	9.38	13.3	1.92	<0.02	99.8
STN-2 Mussels	8/29/07	12.3	9.1	1.52	<0.02	111
STN-3 Mussels	8/29/07	8.81	12.4	1.70	<0.02	85.0
ESL- Mussels	8/29/07	10.5	13.7	1.39	<0.02	96.8

4.2 Data Evaluation

Prior to opening the Greens Creek mine for full production in August 1989, sediment and biota tissues were sampled for heavy metal concentrations. Results for mussels from sites STN-1, STN-2, STN-3 and ESL, and for *Nephtys* from sites S-1 and S-2 from June of 1984 until August of 1989 were used to calculate baseline, pre-production values. These data are useful as baseline values against which to compare metal values after mining began and the results for the current year’s sampling (Table 4-4 and 4-5).

As noted by Oceanographic Institute of Oregon in the 1998 Kennecott Greens Creek Mine Risk Assessment (p 4-3),

> “Sampling stations were selected to demonstrate a range of potential exposures including “worst case” exposure to Outfall discharges. Some of the test organisms placed in cages directly on the Outfall diffuser ports lived for six months. These results indicate that even maximum exposure to the Outfall discharge result in no acute effects.”

TABLE 4-4 Hawk Inlet Mussels Tissue Data: Pre-Production Baseline, Production Period and Current Year Comparison

Metal	**Pre-Production (6/1984-8/1989)**			**Production (9/1989-9/2006)**			**Current Year 2007**		
	Avg	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**
Cd	7.67	3.25	15.76	7.57	<0.5	14.5	**9.33**	6.54	12.3
Cu	8.50	5.5	21.1	7.91	1.3	110	**10.55**	6.5	13.7
Pb	0.572	0.15	1.73	**2.14**	<0.02	92.5	**17.54**	1.15	126
Hg	0.064	0.018	0.56	0.038	<0.02	0.070	0.014	0.02	0.03
Zn	88.39	65.0	142	81.60	49	119	**99.48**	85	111

Data are compilation of results from Stations ESL, STN-1, STN-2 and STN-3

The maximum lead result of 126 mg/kg for STN-2 (Mussels) was shown in the spring of 2007; however, the fall sample at this location was 1.52 mg/kg. The maximum values may have been caused by contamination of the sample during the shucking process. The location for shucking will be modified in 2008. Average lead concentrations in mussel tissues were found 3 to 4 times higher during the production period than the pre-production period. Average lead and zinc in 2007 were higher than the pre-production and production average values. When compared to the Mussel Watch averages for Alaska, cadmium and zinc exceeded these averages (2.87 mg/kg and 87.95 mg/kg, respectively) during pre-production, and cadmium, and lead exceeded these averages (2.87 mg/kg and 1.17 mg/kg, respectively) during production. These levels were similarly noted in the 2003 Review of the Status of Essential Fish Habitat in Hawk Inlet Subsequent to Mining Operations (p 57):

> "…the average mining production period metal levels are generally below Mussel Watch averages for Alaska. The exception to this is Cd, which was above Mussel Watch Alaska averages prior to and subsequent to mining operations. Because the USFWS Hawk Inlet-wide levels of Pb increased similarly to the outfall monitoring site levels of Pb, these increases over time may be due to natural increases in Pb in the environment."

TABLE 4-5 Hawk Inlet *Nephtys* Tissue Data: Pre-Production Baseline, Production Period and Current Year Comparison

Metal	**Pre-Production (6/1984-8/1989)**			**Production (9/1989-9/2006)**			**Current Year 2007**		
	Avg	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**
Cd	2.65	0.24	6.91	1.98	0.28	4.97	2.61	0.92	3.79
Cu	10.24	6.24	17.4	9.45	4.3	27.3	13.78	9.2	22
Pb	0.478	0.13	1.07	1.03	<0.02	4.76	0.7	0.59	0.81
Hg	0.033	0.009	0.074	0.0496	<0.02	1.67	0.0125	<0.02	0.05
Zn	205.9	121	303	183.6	62.6	357	216	181	250

Data are compilation of results from Stations S-1 and S-2

Average lead and mercury concentrations in the indicator polychaete worm, *Nephtys*, increased during production, and lead, copper and zinc were higher in 2007 than the preproduction averages. All metals concentrations will continue to be monitored.

Tables 4-6 and 4-7 show the average and standard deviation results for pre-production and production periods for the individual sites for mussels and *Nephtys*, respectively. Table 4-6 shows larger standard deviations in production levels of lead and copper concentrations in mussels at all sites. Also, copper shows a large increase in standard deviation for the ESL site during post-production sampling. This is thought to be due to a single extreme value of 110 mg/kg dw from 1992. Table 4-7 shows larger standard deviations in production levels of lead concentrations in Nephtys at S-1, S-2 and S-4.

TABLE 4-6 Average and Standard Deviation Values for Pre-Production and Production Mussel Data

Metal (mg/kg dw)	ESL				STN-1				STN-2			
	pre-production (9/1984-8/1989)		production (9/1989 - 9/2006)		pre-production (9/1984-8/1989)		production (9/1989 - 9/2006)		pre-production (9/1984-8/1989)		production (9/1989 - 9/2006)	
	avg	stdev	avg	stdev	avg	stdev	avg	stdev	avg	stdev	avg	stdev
Cd	6.17	1.782	6.12	1.724	7.483	1.718	**7.56**	1.922	8.01	3.006	**8.57**	2.51
Cu	9.61	3.77	**9.77**	17.55	8.05	1.19	7.12	1.47	7.82	1.02	7.55	2.96
Pb	0.526	0.260	**1.341**	0.799	0.661	0.437	**1.38**	0.930	0.453	0.269	**1.74**	1.72
Hg	0.0344	0.0119	**0.0435**	0.0850	0.1014	0.1421	0.0372	0.0169	0.0378	0.0122	0.0342	0.0207
Zn	90.22	8.07	77.9	18.90	88.53	15.44	82.2	14.36	83.02	14.53	82.0	17.4

Metal (mg/kg dw)	STN-3			
	pre-production (9/1984-8/1989)		production (9/1989 - 9/2006)	
	avg	stdev	avg	stdev
Cd	9.00	2.81	8.03	2.01
Cu	8.54	1.58	7.20	1.98
Pb	0.65	0.24	**4.09**	15.6
Hg	0.084	0.150	0.036	0.020
Zn	91.8	17.92	83.8	17.07

Underlined/bolded concentrations are higher than pre-production averages

TABLE 4-7 Average and Standard Deviation Values for Pre-Production and Production *Nephtys* Data

Metal (mg/kg dw)	S-1 *Nephtys*				S-2 *Nephtys*			
	pre-production (9/1984-8/1989)		production (9/1989 - 9/2006)		pre-production (9/1984-8/1989)		production (9/1989 - 9/2006)	
	avg	stdev	avg	stdev	avg	stdev	avg	stdev
Cd	3.91	1.72	2.81	0.907	1.396	0.846	1.142	0.517
Cu	9.27	1.41	**9.96**	4.31	11.21	3.56	8.94	3.96
Pb	0.452	0.157	**1.26**	1.10	0.503	0.258	**0.795**	0.481
Hg	0.0465	0.0103	0.0387	0.0233	0.019	0.0077	**0.0605**	0.281
Zn	243.3	43.0	204.6	44.1	168.6	34.4	162.5	40.9

Metal (mg/kg dw)	S-4 *Nephtys*			
	pre-production (9/1984-8/1989)		production (9/1989 - 9/2006)	
	avg	stdev	avg	stdev
Cd	0.926	0.723	**1.29**	0.71
Cu	21.0	9.25	**28.2**	21.5
Pb	3.65	1.08	**13.8**	14.9
Hg	0.06	0.062	0.027	0.023
Zn	210.2	17.9	205.0	65.8

Underlined/bolded concentrations are higher than pre-production averages

Additional tissue samples of *Cockles and Littlenecks* were collected in 2007. Table 4-8 summarizes the average metal values for the available data for these additional tissue samples. Only *Cockles* at site S-4 has pre-production period data available for comparison (Table 4-8).

TABLE 4-8 Summary of Results for Additional Tissue Samples

Metal-average (mg/kg dw)	S-2 *Cockles*	S-2 *Littlenecks*	S-4 *Cockles*	
	(1999-2007)	(1999-2007)	(5/84-7/89)	(9/89-2007)
Cd	0.737	2.27	0.714	0.69
Cu	9.94	8.30	9.27	7.46
Pb	0.614	0.463	9.92	7.95
Hg	0.014	0.016	0.036	0.030
Zn	68.5	80.8	100.1	78.6

Effluent toxicity testing, conducted since the mining operations began, was discontinued in 2005 with re-issuance of the NPDES Permit (AK-004320-6). Over the 21 years of initially acute toxicity testing (February 1989 – October 1998), and then chronic toxicity testing (November 1998 – June 2005) no sublethal deleterious effects to tested marine aquatic organisms from prolonged exposure to the treated KGCMC effluent was determined to be likely:

> "The data show that the effluent from Outfall 002 has no reasonable potential to contribute to an exceedence of the (Alaska) WQS for toxicity." (USEPA Fact Sheet dated October 28, 2004; page 14, Section VI.B Whole Effluent Toxicity Testing).

4.3 QA/QC Results

Columbia Analytical Laboratory analyzed the required parameters (see Table 1-1) in the bioassay samples. Complete QA plans and reports are kept on file in the lab's office and are available upon request. The remainder of this section summarizes the relevant QA/QC results for the spring and fall sampling events in 2007.

Spring 2007: All predetermined data quality objectives for the laboratory's QA/QC plan were met for these samples: all duplicates, blanks, spikes and lab control samples were within control limits for tissue samples.

Fall 2007: The control criteria for matrix spike recovery of zinc for sample S-4 *Nephtys* I are not applicable. The analyte concentration in the sample was significantly higher that the added spike concentration, preventing accurate evaluation of the spike recovery.

The control criteria for matrix spike recoveries of cadmium and zinc for sample STN-2 Mussels are not applicable. The analyte concentration in the sample was significantly higher than the added spike concentration, preventing accurate evaluation of the spike recovery.

Beginning in the fall of 2004, duplicate samples have been collected from each site, where possible, to address a National Marine Fisheries Service request. Precision can be calculated from the results of duplicate samples. In this case, the relative standard deviation RSD (the standard deviation relative to the mean, expressed as a percent) is shown for the duplicate samples in Table 4-9. The data quality objectives for the RSD are less than or equal to 30 percent, when the values are at least four times the detection limit. Two out of the 24 (approximately 8 percent) of the RSDs calculated for the 2007 duplicate samples was not within this data quality objective (Cu, S-1 and S-4). This results in greater than 90 percent completeness, which is acceptable for tissue duplicate samples.

TABLE 4-9 Relative Standard Deviation (RSD) for Duplicate Tissue Samples

SAMPLE ID	DATE	Cd	Cu	Pb	Hg	Zn
		(mg/kg dw)	(mg/kg dw)	(mg/kg dw)	(mg/kg dw)	(mg/kg dw)
S-1 Nephtys I	6/14/07	3.36	12.9	0.81	0.05	250
S-1 Nephtys II	6/14/07	3.46	13	1	0.04	250
S-1 Nephtys III	6/14/07	3.1	10.9	0.86	0.05	235
RSD		***5.62***	***9.66***	***11.07***	***--***	***3.53***
S-2 Nephtys I	6/14/07	0.92	9.2	0.78	<0.02	181
S-2 Nephtys II	6/14/07	1.09	11	0.94	<0.02	195
S-2 Nephtys III	6/14/07	1.08	10.8	0.93	<0.02	185
RSD		***9.26***	***9.55***	***10.15***	***--***	***3.86***
S-4 Nephtys I	6/14/07	0.92	9.2	0.78	<0.02	181
S-4 Nephtys II	6/14/07	1.09	11	0.94	<0.02	195
S-4 Nephtys III	6/14/07	1.08	10.8	0.93	<0.02	185
RSD		***9.26***	***9.55***	***10.15***	***--***	***3.86***
S-1 Nephtys I	8/29/07	3.79	22	0.62	<0.02	234
S-1 Nephtys II	8/29/07	3.15	13	0.71	0.08	285
S-1 Nephtys III	8/29/07	4	13.7	0.88	0.05	274
RSD		***12.14***	***30.8***	***17.92***	***--***	***10.15***
S-2 Nephtys I	8/30/07	2.37	11	0.59	<0.02	199
S-2 Nephtys II	8/30/07	3.46	14.7	0.59	<0.02	261
S-2 Nephyts III	8/30/07	3.17	15.3	0.56	0.03	267
RSD		***18.8***	***17.04***	***2.99***	***--***	***15.54***
S-4 Nephtys I	8/28/07	0.37	10.3	4.77	<0.02	207
S-4 Nephtys II	8/28/07	0.5	20.3	4.4	<0.02	191
S-4 Nephtys III	8/28/07	0.38	26	4.3	<0.02	166
RSD		***17.36***	***42.1***	***5.51***	***--***	***10.99***

-- Indicates the RSD was not calculated because one or more of the results was not greater than four times the detection limit (DL)

5.0 CONCLUSIONS

The current status of the health of marine and aquatic ecosystems can be viewed based on the number of types of species present in an area (species diversity, or “biodiversity”), the number of individuals from each species in an area (species abundance), and quality of the environment (habitat integrity relative to pristine conditions).

For the marine environment, there are no data available to numerically compare diversity or abundance of organisms between pre-mining and post-mining years. Observations by fishermen and researchers suggest that the physical features and biotic communities of Hawk Inlet remain intact following nearly 12 years of operation of the mine and they remain similar to adjacent inlets (Ridgeway, 2003). Halibut and crab numbers are reported to have declined significantly with the closing of the fish processing facilities which previously operated at the now Hawk Inlet Cannery which now provides the KGCMC port facilities.

Marine species which consume sedentary seafloor organisms such as worms and bivalves would be most susceptible to trophic transfer of some metals. Based on the suite of species listed as having Essential Fish Habitat in Hawk Inlet, the species most likely to encounter these elevated metal levels through their diet and habitat uses would include the flatfishes (*e.g.* yellowfin sole, arrowtooth flounder, flathead sole, and rock sole), pacific cod, sculpin and crab species. Pacific halibut also have similar consumption patterns to these species. All of these species consume worms, bivalves, and crab.

Other migratory and resident fish, mammals, and birds which consume seafloor-dwelling organisms near the ore loading dock would also likely encounter elevated metal levels in their diet in restricted sites within Hawk Inlet. There are no data available to evaluate whether metals are increasing through trophic transfer, or biomagnification at higher trophic levels in Hawk Inlet marine species such as fish, crab and mammals. However, given the mobility of the afore-mentioned species, and the restricted KGCMC-associated locations of higher metal loading, it is unlikely that any of these species would show a significant effect attributable to mining activities in the vicinity of Hawk Inlet.

6.0 REFERENCES

Greens Creek Tailings Disposal: Final Environmental Impact Statement; USDA Forest Service, November 2003.

Kennecott Greens Creek Mining Company, Hawk Inlet Monitoring Program 2005 Annual Report, January 2006.

Kennecott Greens Creek Mining Company, Hawk Inlet Monitoring Program 2006 Annual Report, April 2007.

Kennecott Greens Creek Mine Risk Assessment NPDES Permit No. AK-004320-6, Admiralty Island, Alaska, Oregon Institute of Oceanography, and Remediation Technologies, Inc. June 22, 1998

National Pollutant Discharge Elimination System (NPDES) permit AK-004320-6, USEPA, effective date July 1, 2005.

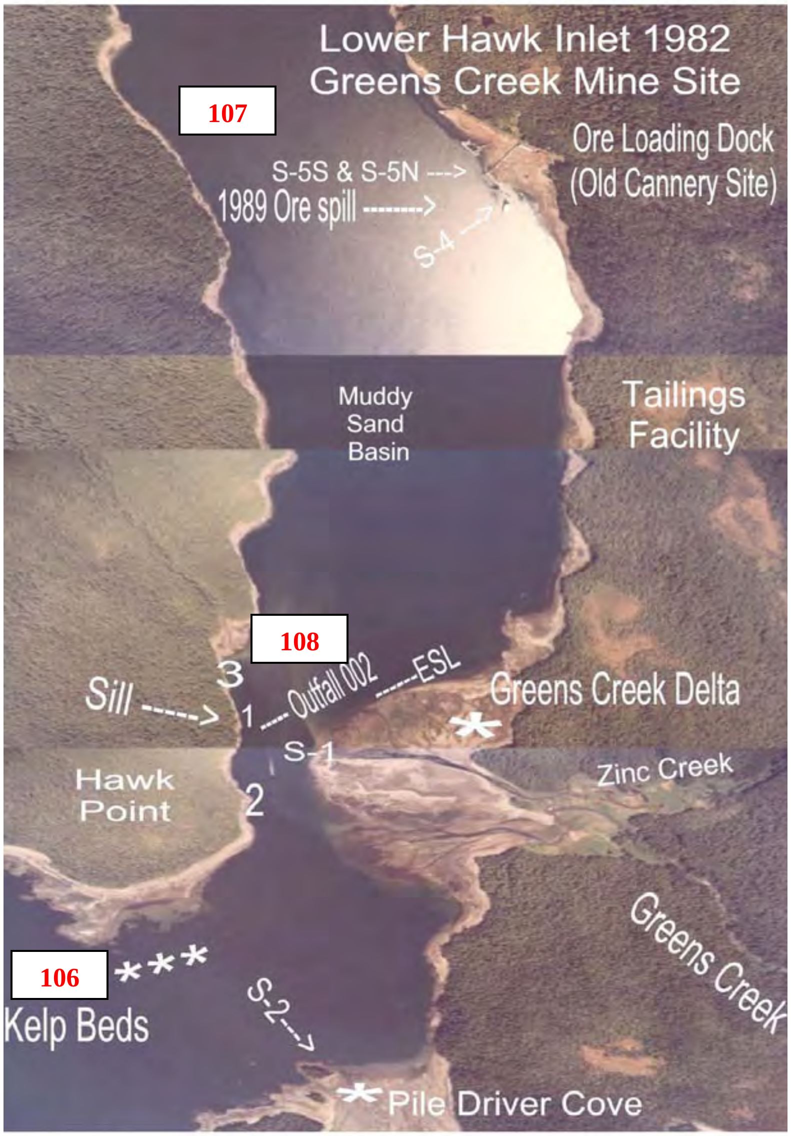
NPDES Quality Assurance Project Plan (QAPP), KGCMC, August 2005.

Oregon Institute of Oceanography (OIO) 1984 – 2002. Laboratory Results of Semi-Annual NPDES sediment and mussel tissue sampling in Hawk Inlet, Alaska. Columbia Analytical Lab Data for years 1984-2002.

Technical Review of the Status of Essential Fish Habitat in Hawk Inlet Subsequent to Mining Operations, M. Ridgeway, Oceanus Alaska, October 2003.

FIGURES

FIGURE 1-1 Aerial Photo of Lower Hawk Inlet, Admiralty Island with Water, Sediment and Tissue Sampling Site Locations



NOTES: Sites 106, 107 and 108 are sea water sampling sites.
S-1, S-2, S-4 and S-5 are sediment and *Nephtys* and *Nereis* sampling sites.
(Station S-3 – not shown – is at the head of Hawk Inlet.)
Stations 1, 2, 3 and ESL are mussel sampling sites.

FIGURE 2-1a

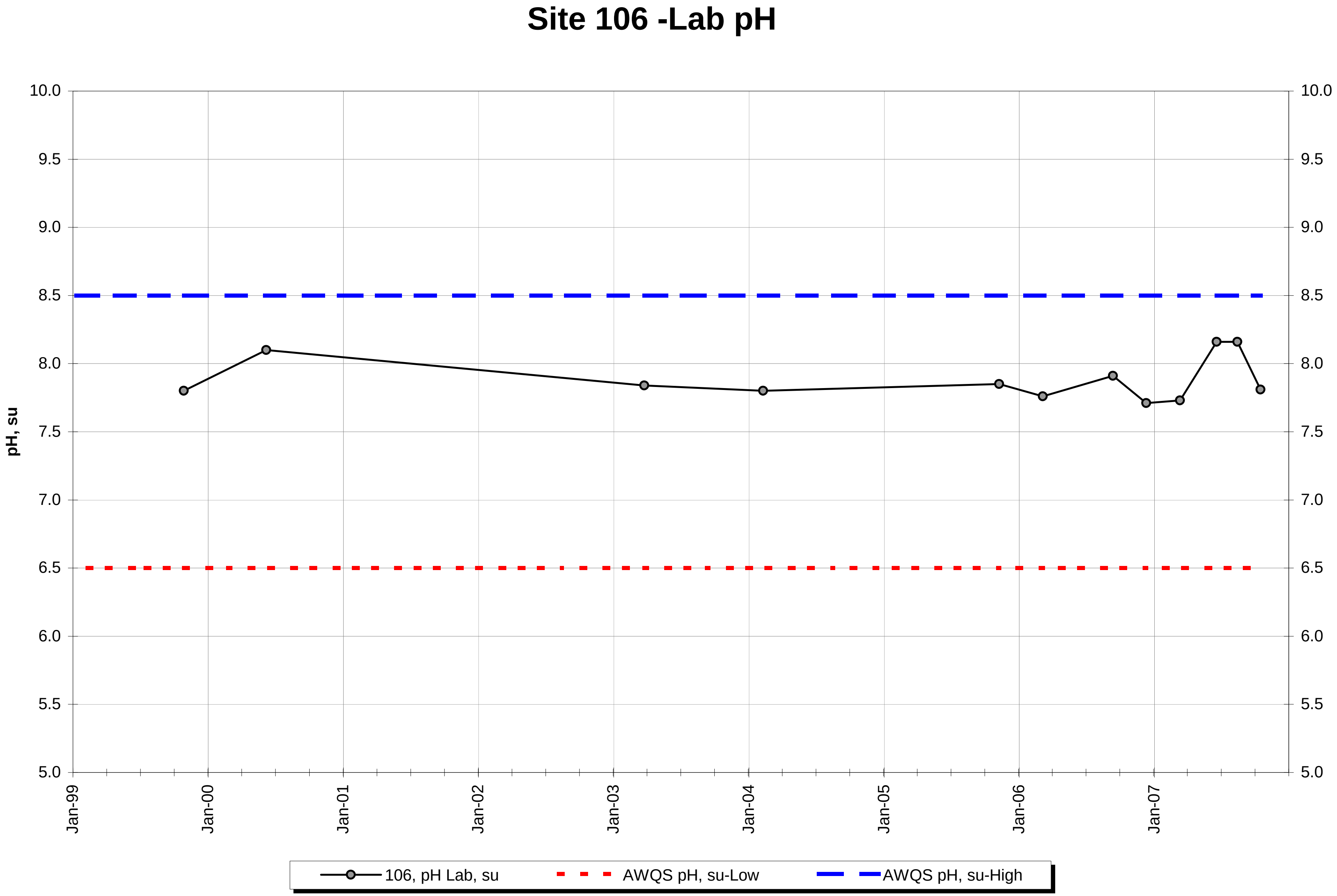

Site 106 -Lab pH
pH, su
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
106, pH Lab, su
AWQS pH, su-Low
AWQS pH, su-High

FIGURE 2-1b

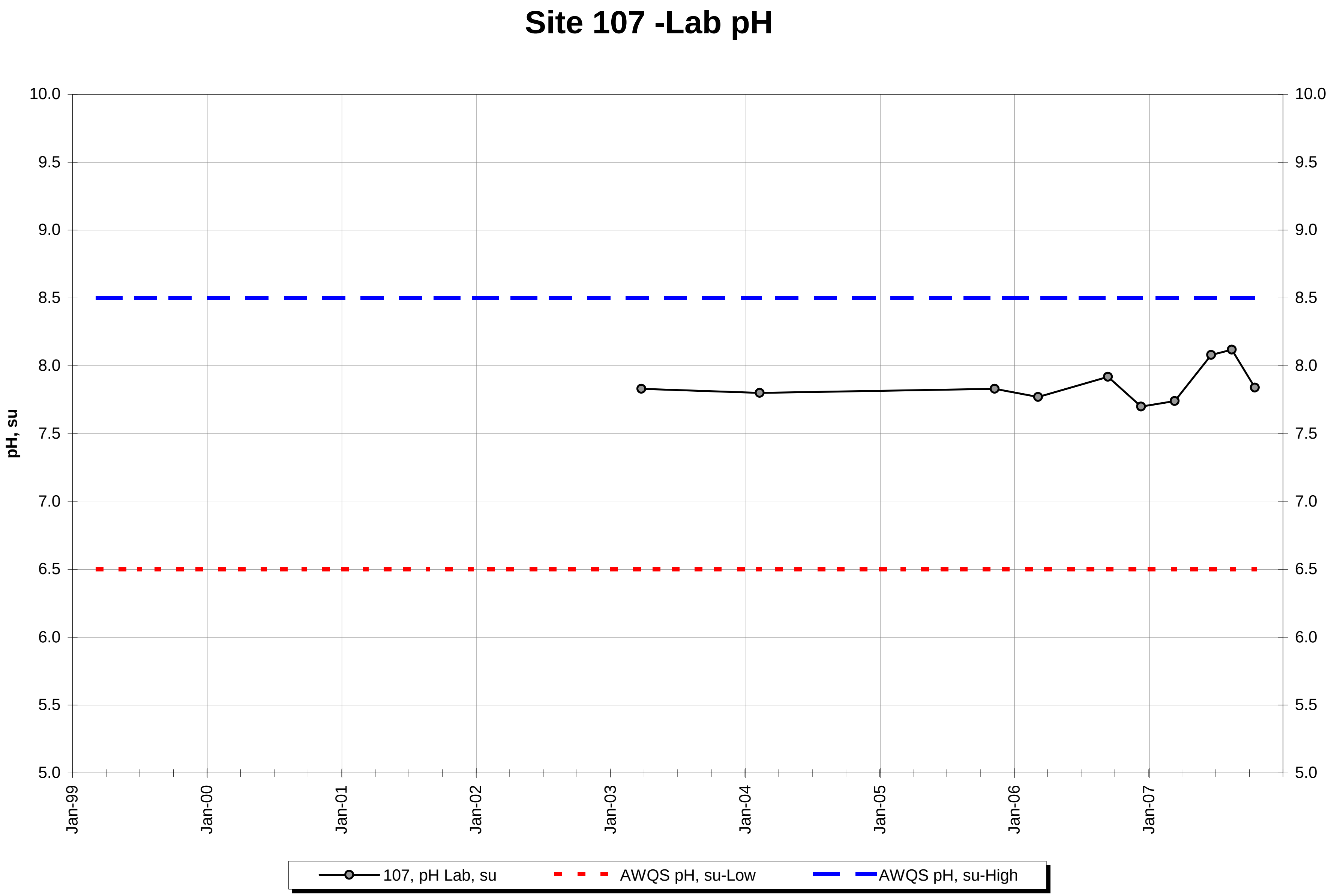

Site 107 -Lab pH
pH, su
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
107, pH Lab, su
AWQS pH, su-Low
AWQS pH, su-High

FIGURE 2-1c

Site 108 -Lab pH

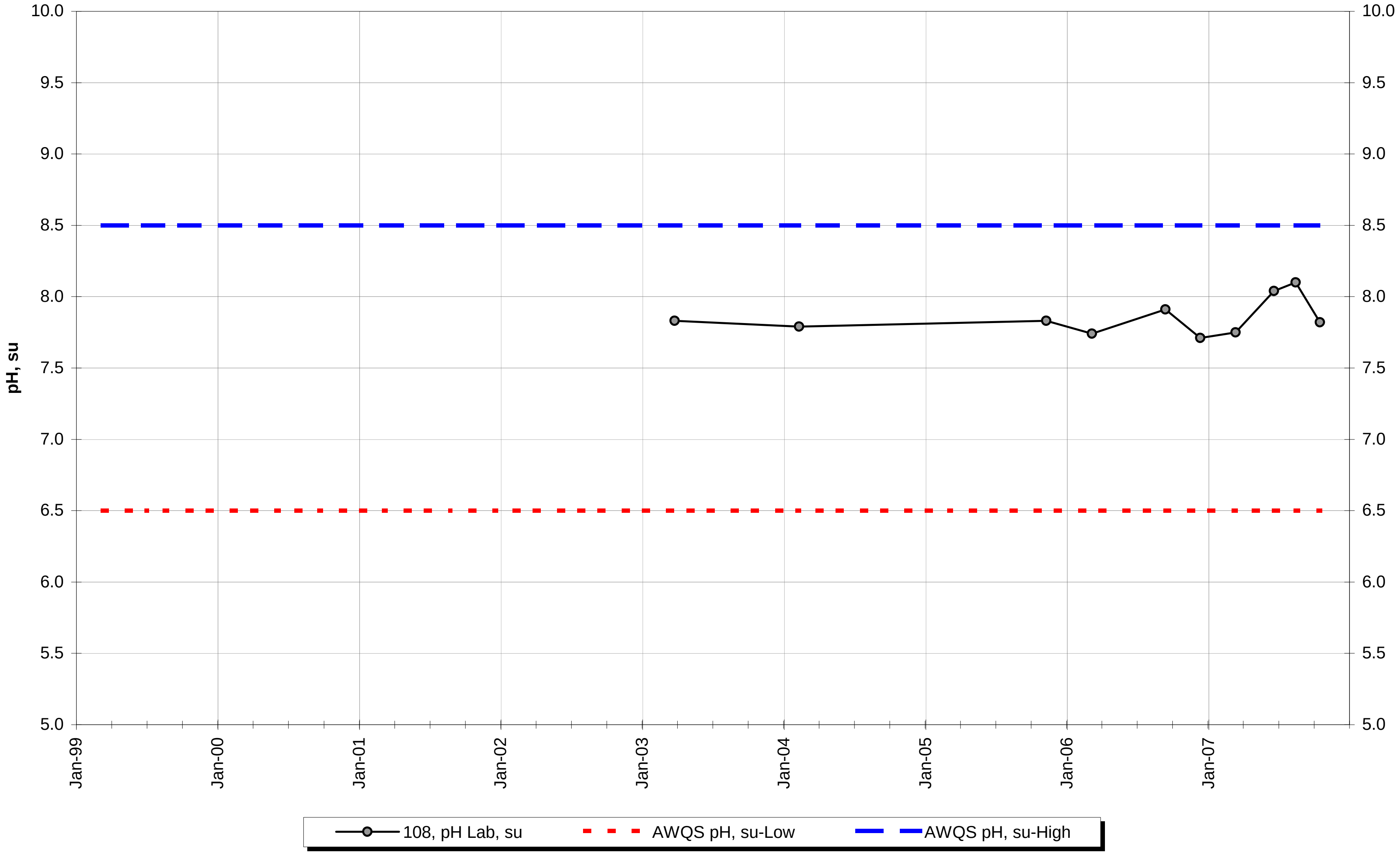


FIGURE 2-2a

Site 106 -Field Conductivity

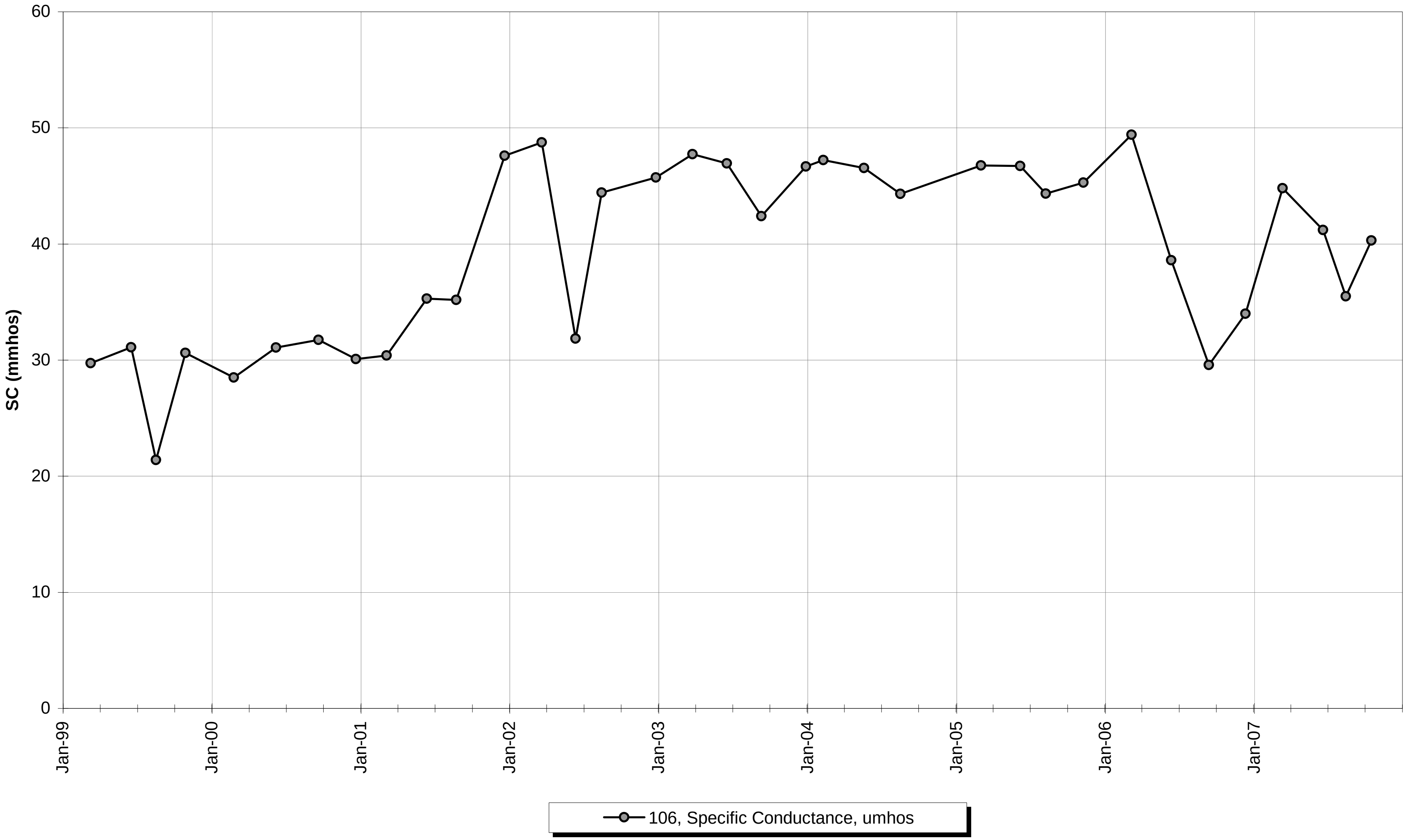


FIGURE 2-2b

Site 107 -Field Conductivity

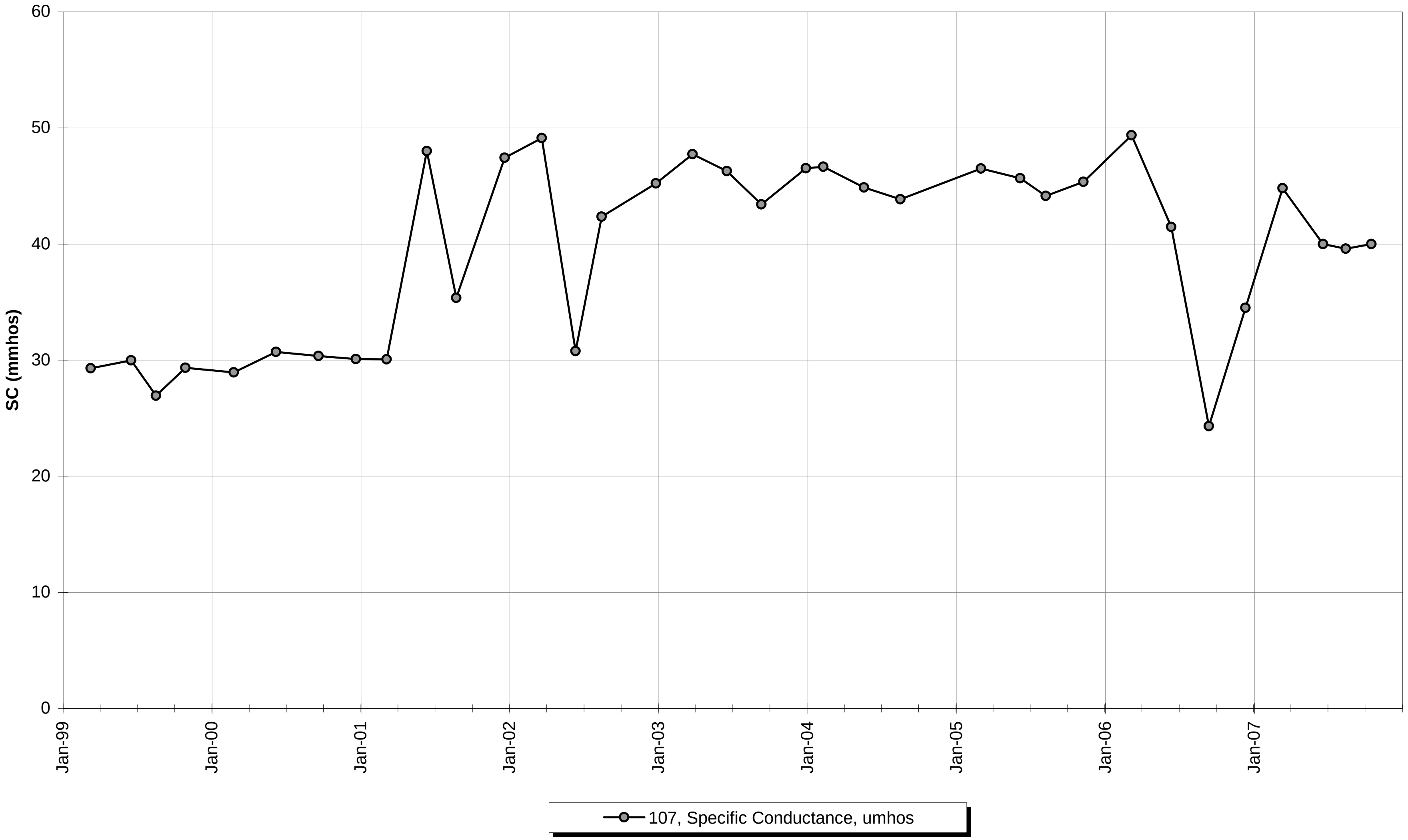


FIGURE 2-2c

Site 108 -Field Conductivity

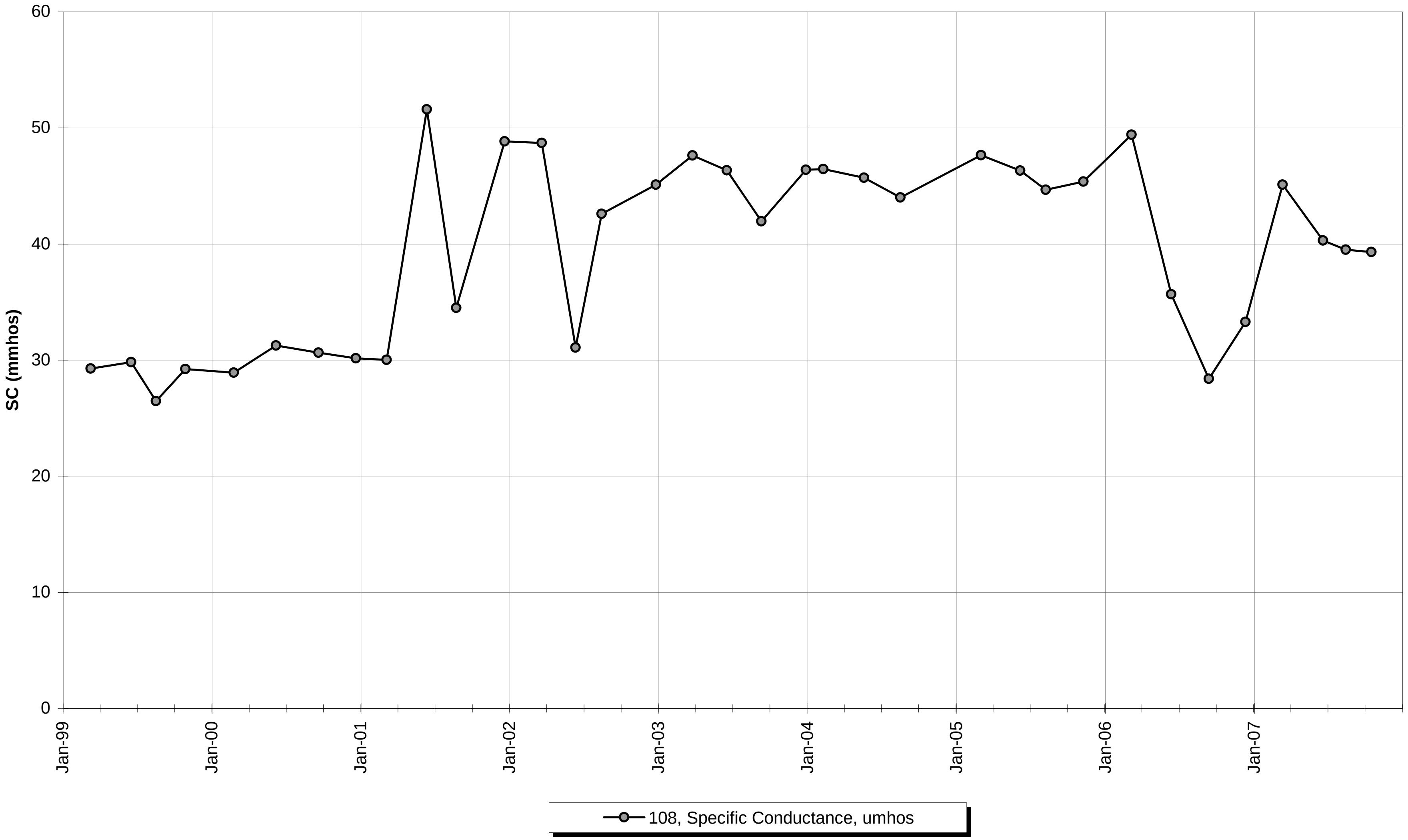
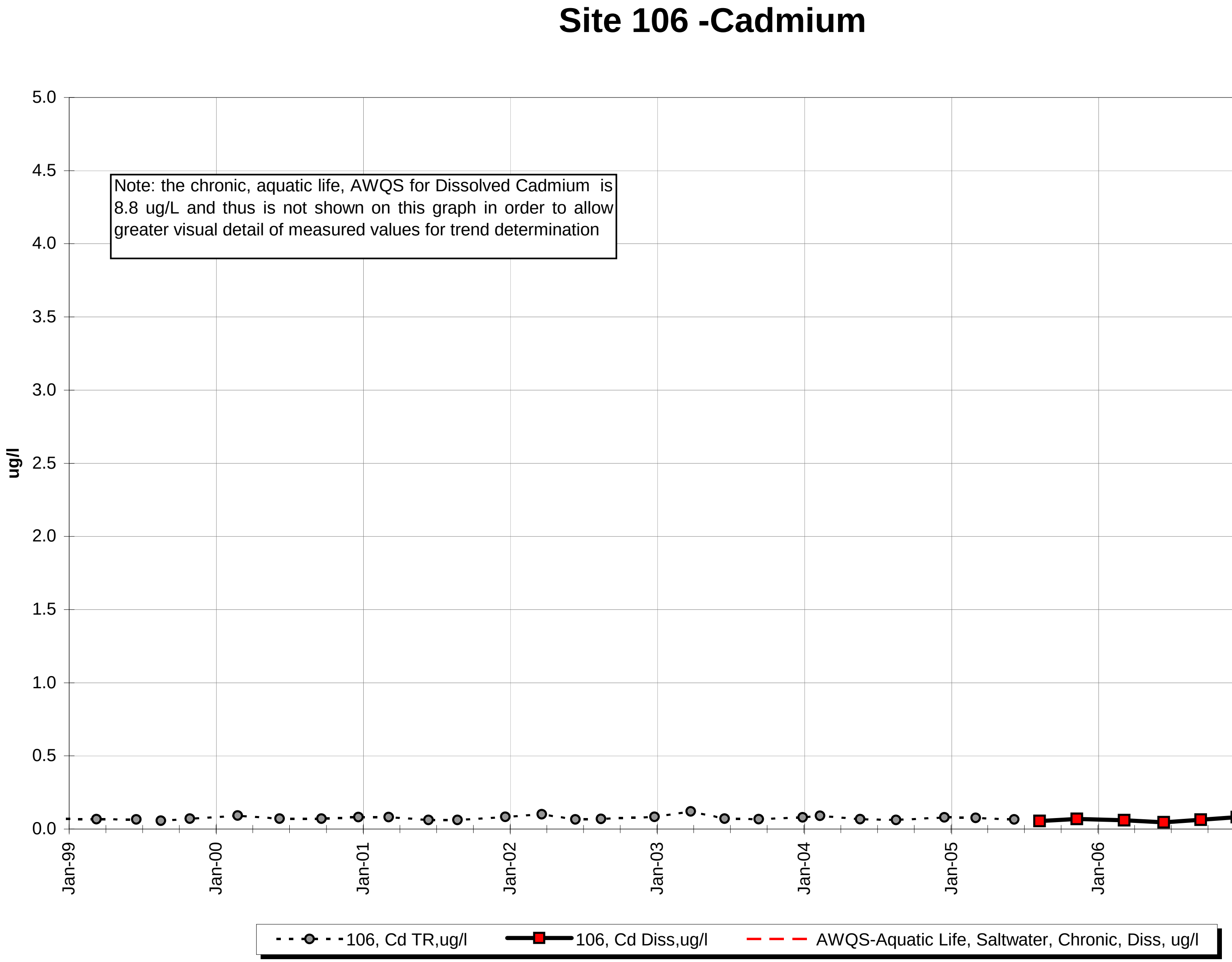
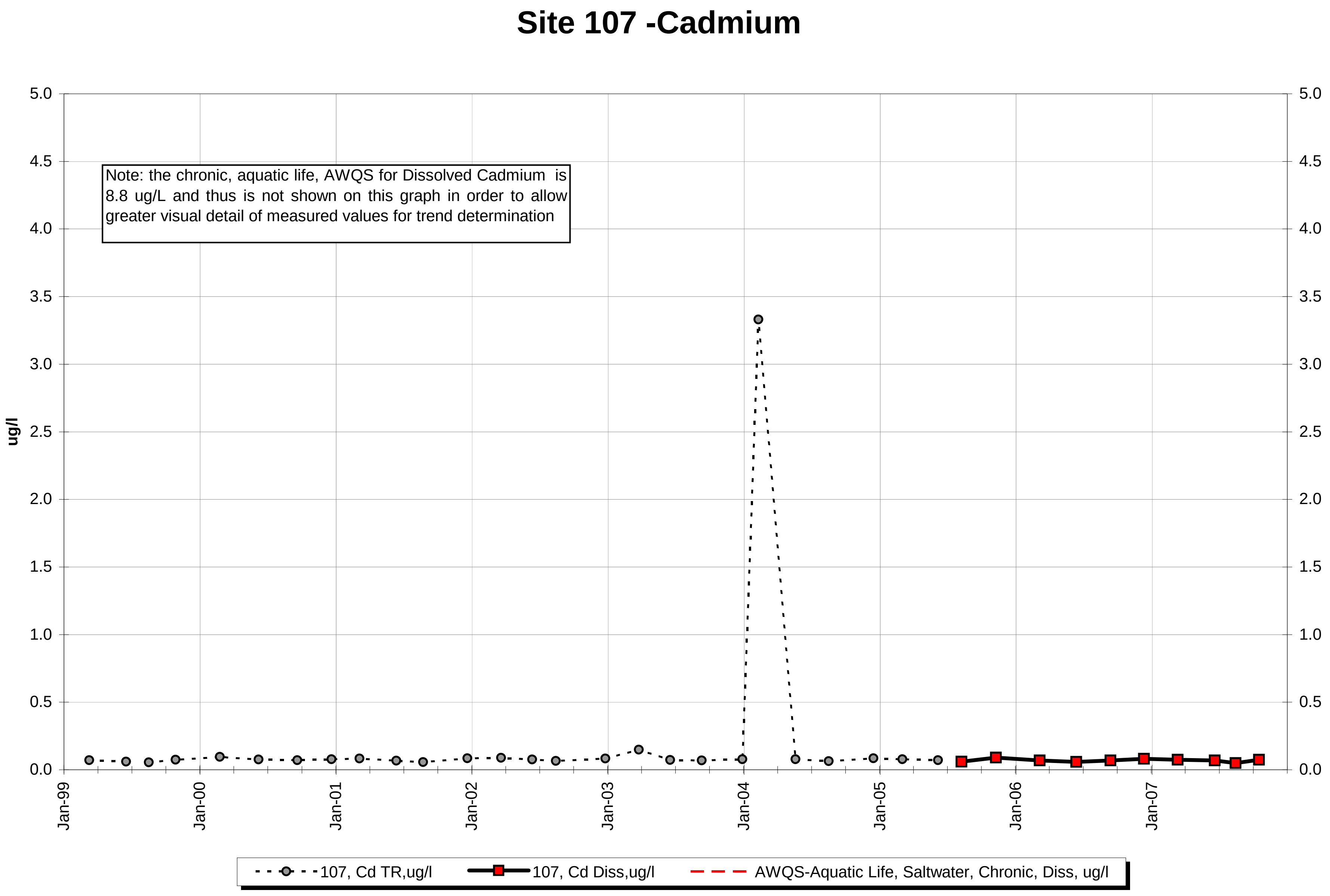


FIGURE 2-3a



Note: the chronic, aquatic life, AWQS for Dissolved Cadmium is 8.8 ug/L and thus is not shown on this graph in order to allow greater visual detail of measured values for trend determination

FIGURE 2-3b



Note: the chronic, aquatic life, AWQS for Dissolved Cadmium is 8.8 ug/L and thus is not shown on this graph in order to allow greater visual detail of measured values for trend determination

FIGURE 2-3c

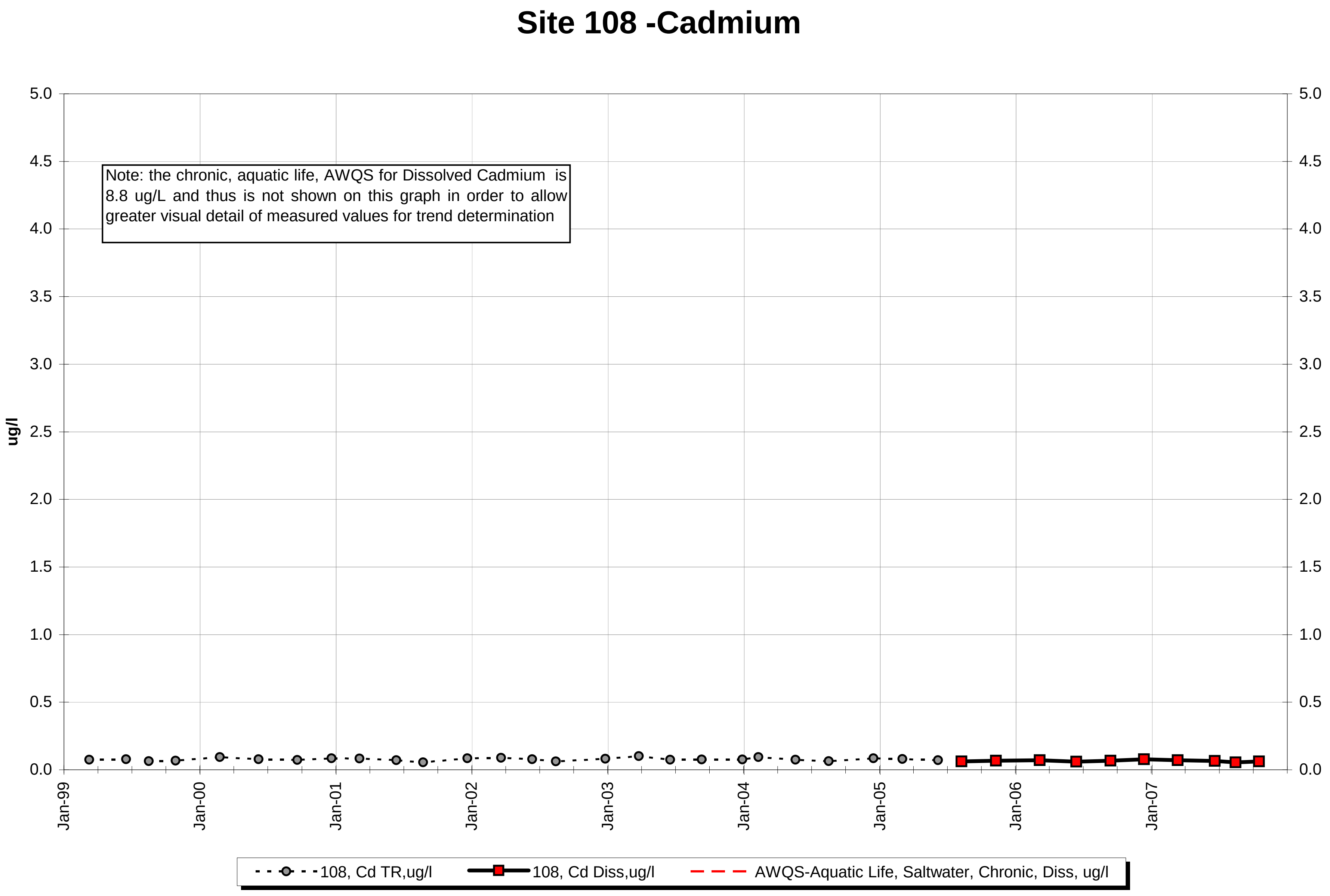

Site 108 -Cadmium
Note: the chronic, aquatic life, AWQS for Dissolved Cadmium is 8.8 ug/L and thus is not shown on this graph in order to allow greater visual detail of measured values for trend determination
ug/l
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
108, Cd TR,ug/l
108, Cd Diss,ug/l
AWQS-Aquatic Life, Saltwater, Chronic, Diss, ug/l

FIGURE 2-4a

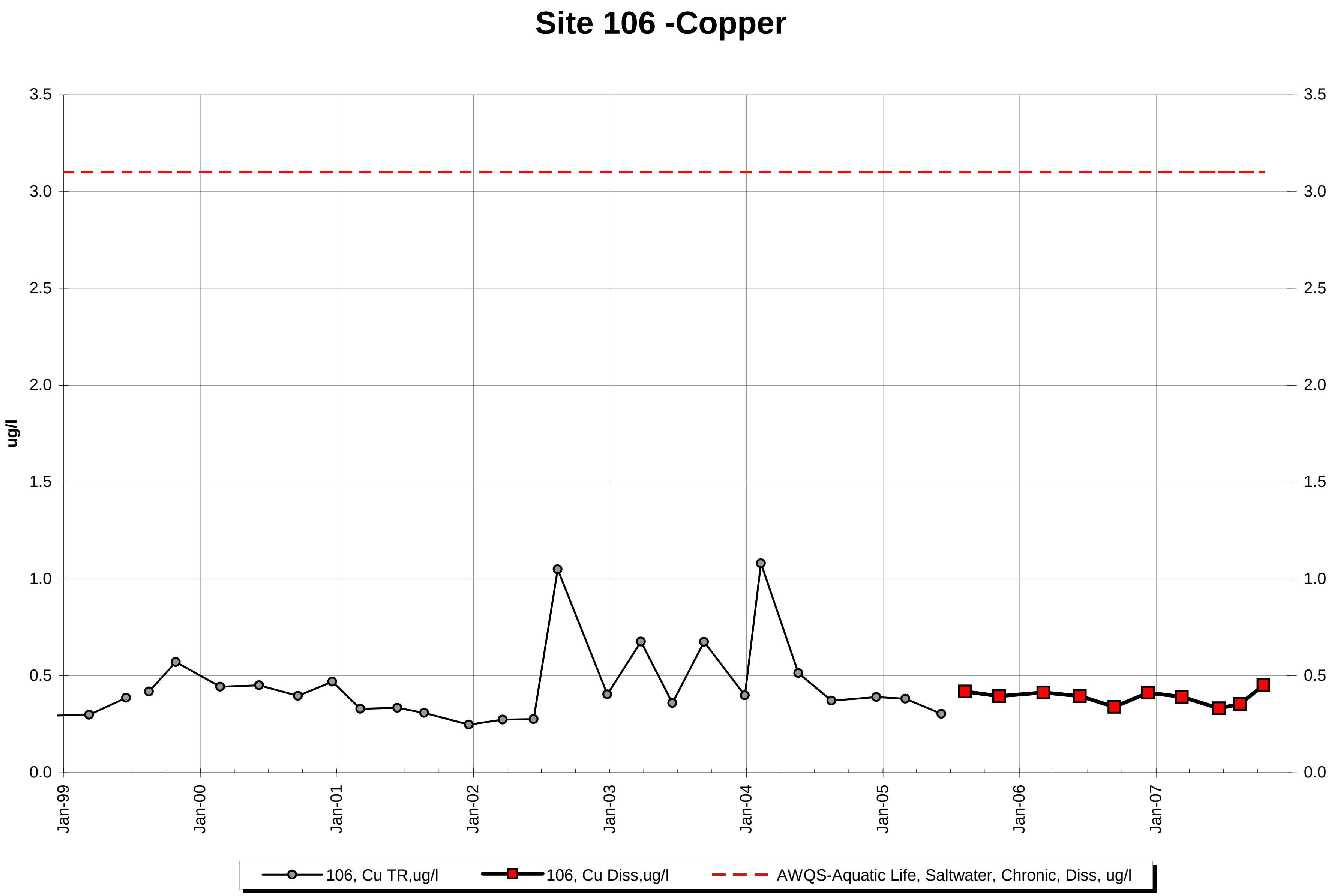

Site 106 -Copper
ug/l
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
106, Cu TR,ug/l
106, Cu Diss,ug/l
AWQS-Aquatic Life, Saltwater, Chronic, Diss, ug/l

FIGURE 2-4b

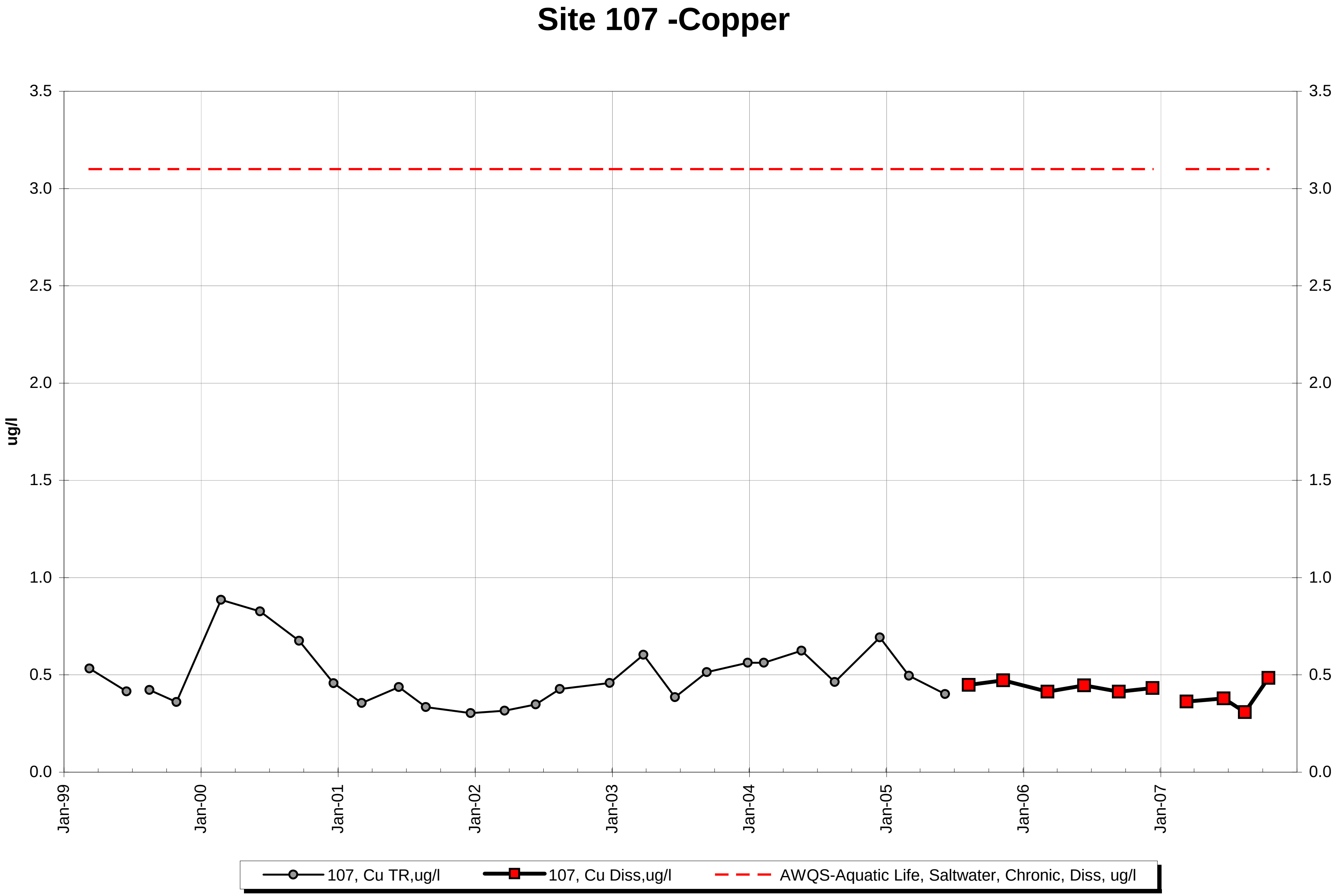

Site 107 -Copper
ug/l
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
107, Cu TR,ug/l
107, Cu Diss,ug/l
AWQS-Aquatic Life, Saltwater, Chronic, Diss, ug/l

FIGURE 2-4c

Site 108 -Copper

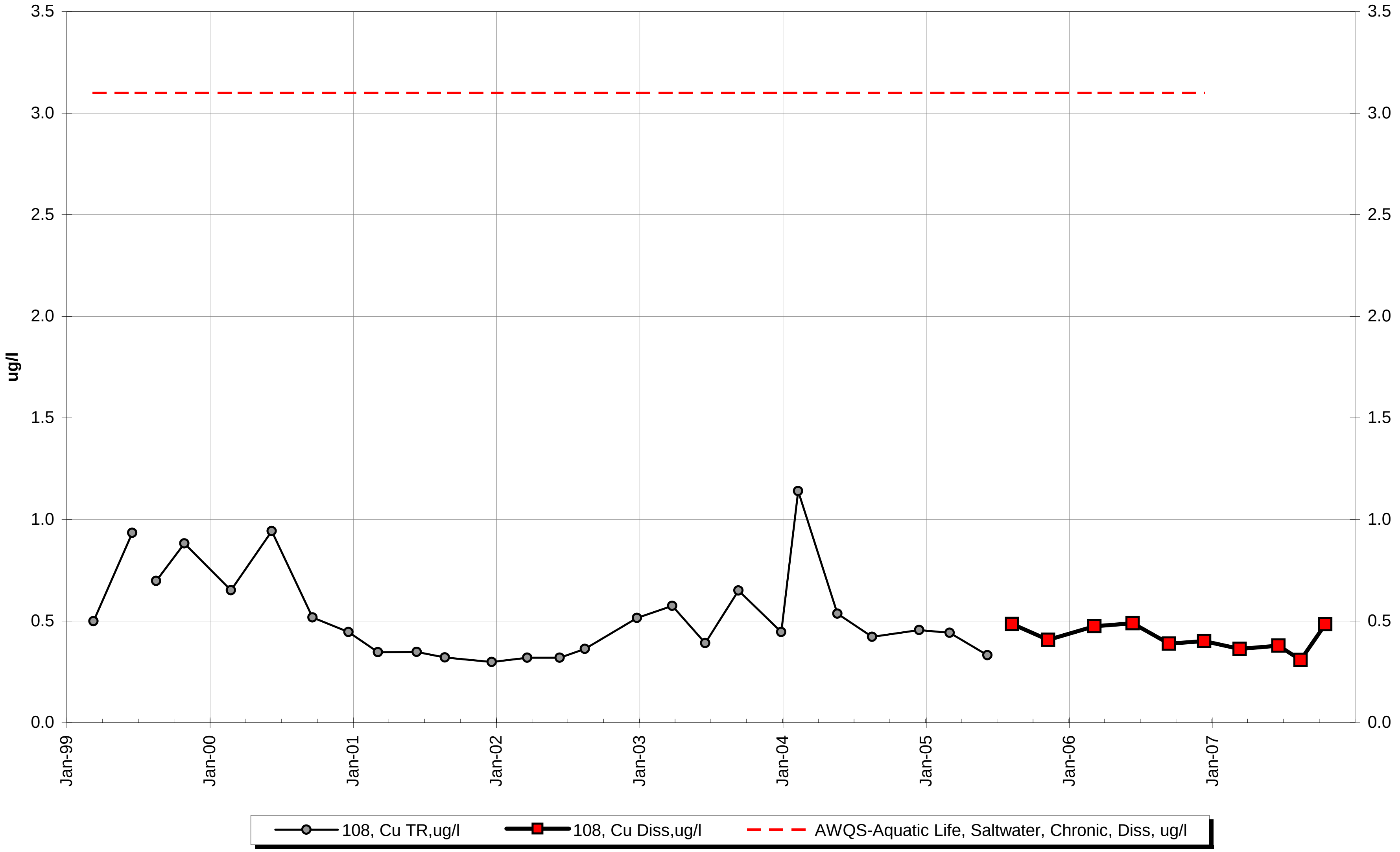


FIGURE 2-5a

Site 106 -Mercury

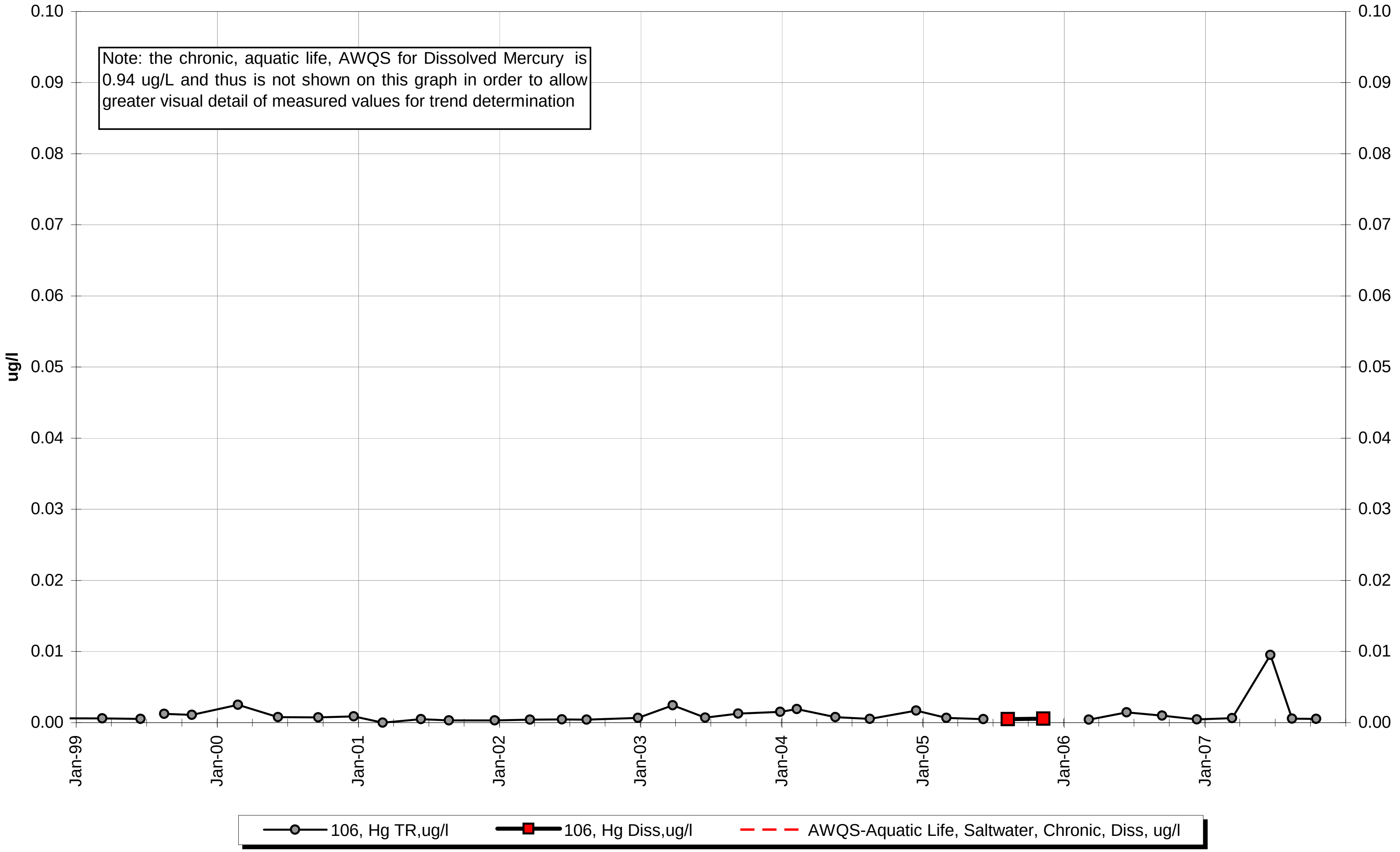


FIGURE 2-5b

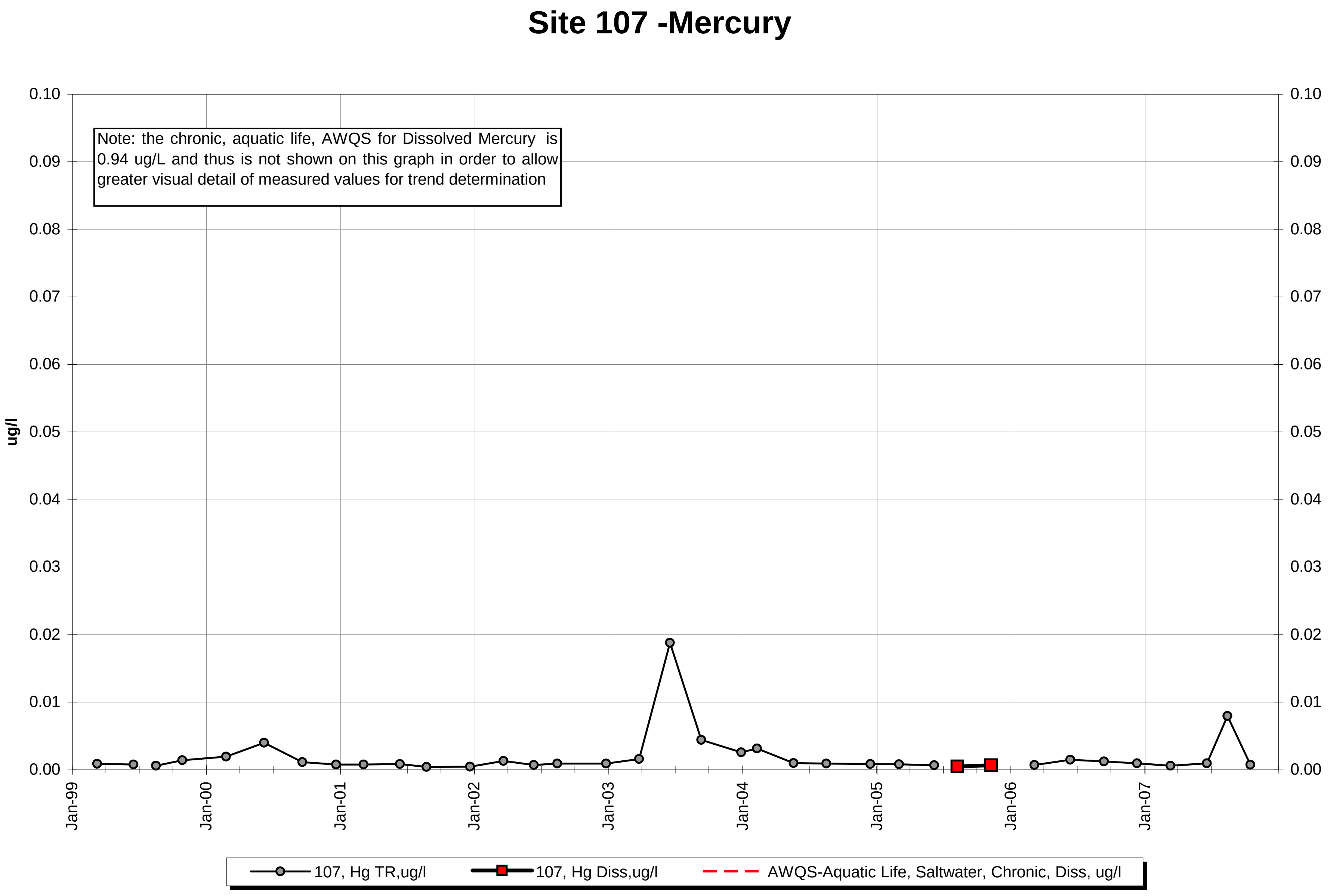

Site 107 -Mercury
Note: the chronic, aquatic life, AWQS for Dissolved Mercury is 0.94 ug/L and thus is not shown on this graph in order to allow greater visual detail of measured values for trend determination
ug/l
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
107, Hg TR,ug/l
107, Hg Diss,ug/l
AWQS-Aquatic Life, Saltwater, Chronic, Diss, ug/l

FIGURE 2-5c

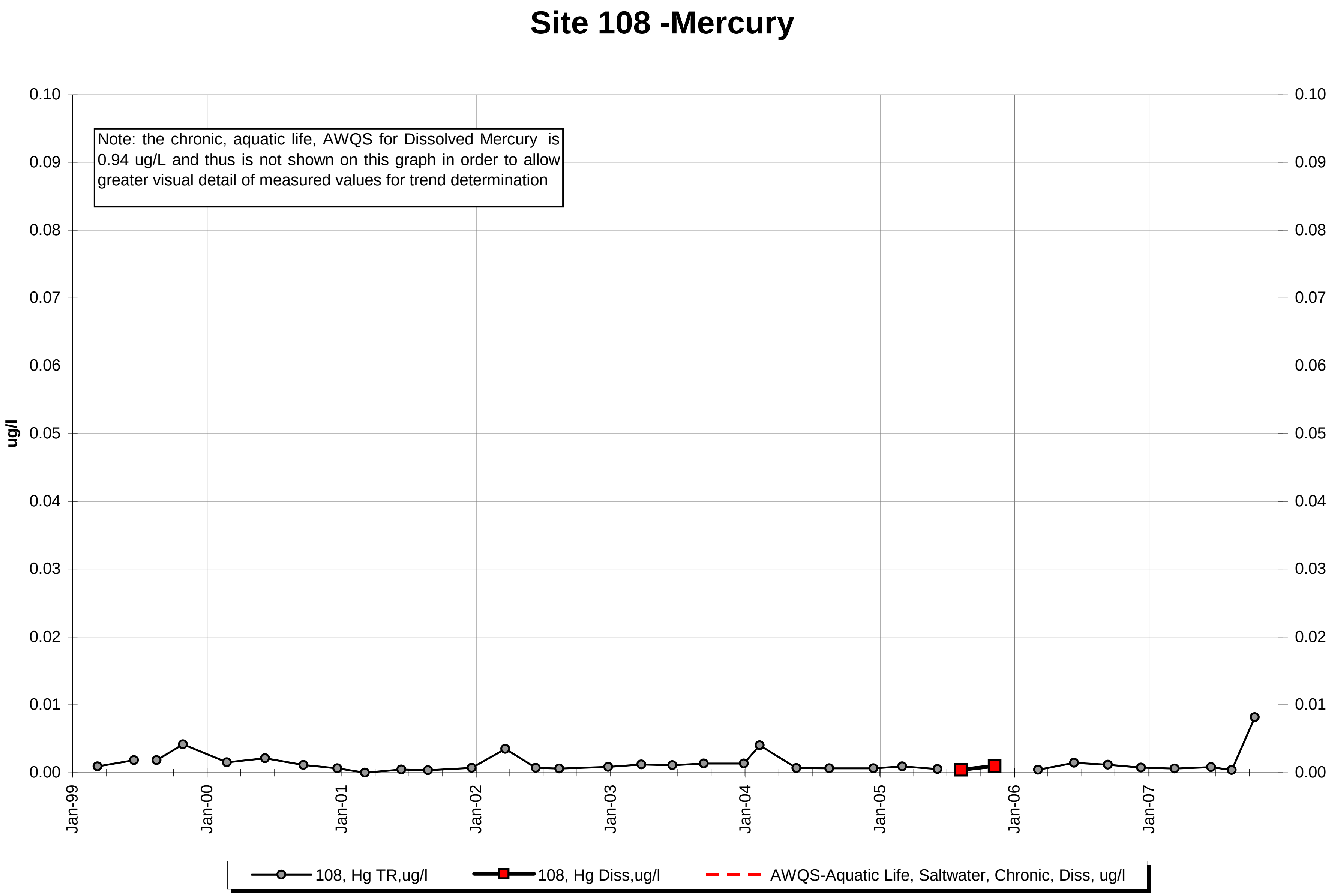

Site 108 -Mercury
Note: the chronic, aquatic life, AWQS for Dissolved Mercury is 0.94 ug/L and thus is not shown on this graph in order to allow greater visual detail of measured values for trend determination
ug/l
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
108, Hg TR,ug/l
108, Hg Diss,ug/l
AWQS-Aquatic Life, Saltwater, Chronic, Diss, ug/l

FIGURE 2-6a

Site 106 -Lead

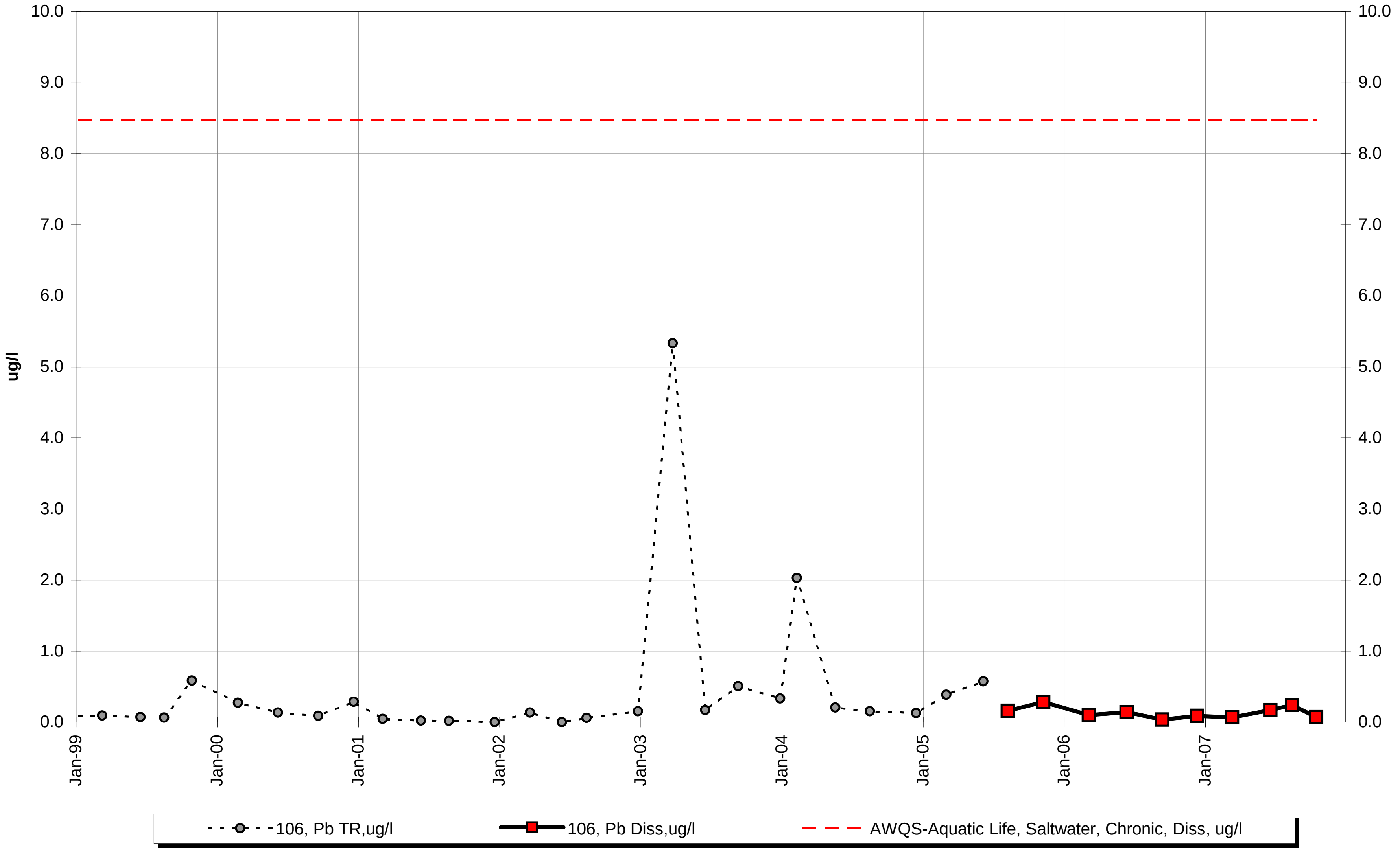


FIGURE 2-6b

Site 107 -Lead

FIGURE 2-6c

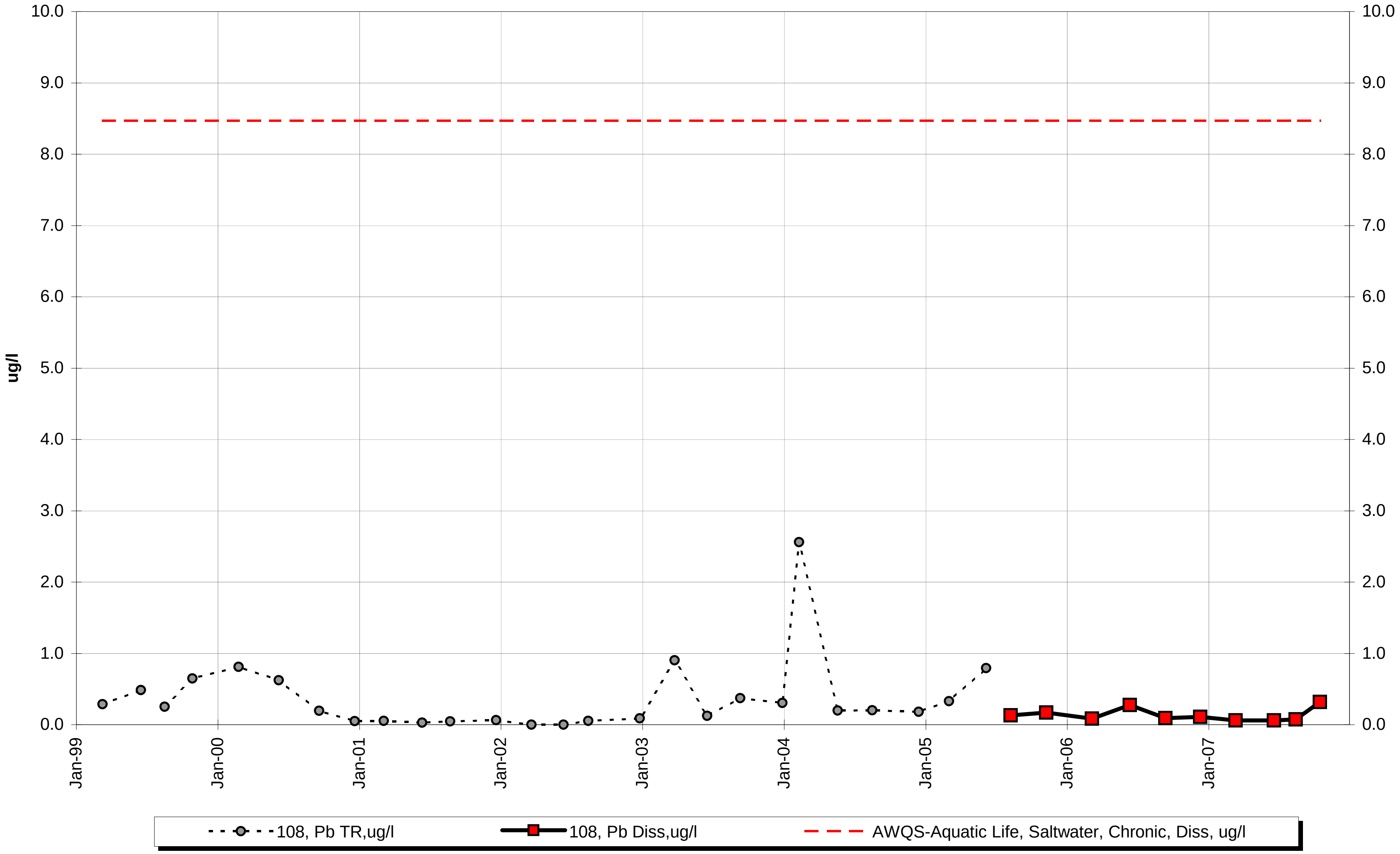

Site 108 -Lead
ug/l
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
108, Pb TR,ug/l
108, Pb Diss,ug/l
AWQS-Aquatic Life, Saltwater, Chronic, Diss, ug/l

FIGURE 2-7a

Site 106 -Zinc

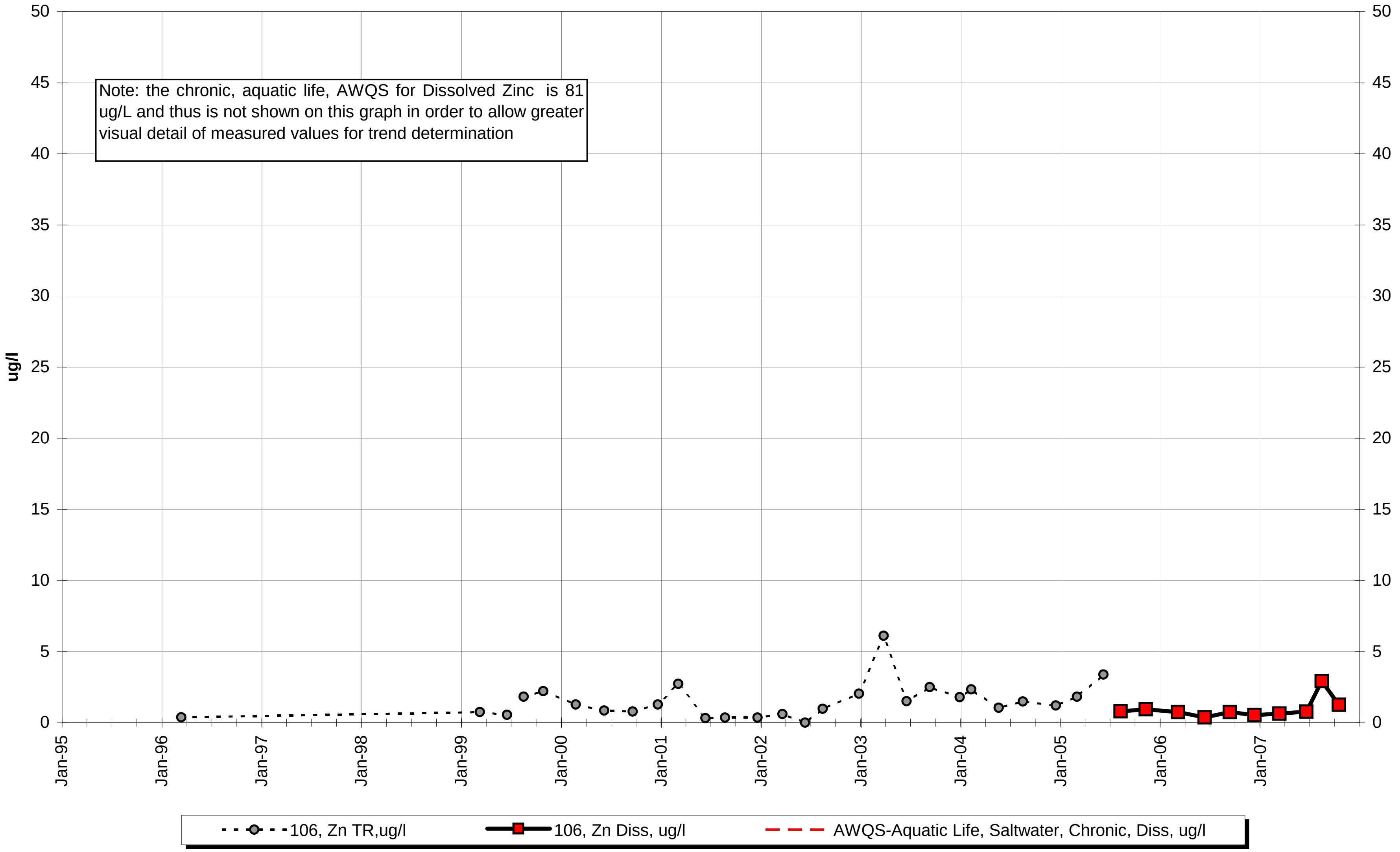


FIGURE 2-7b

Site 107 -Zinc

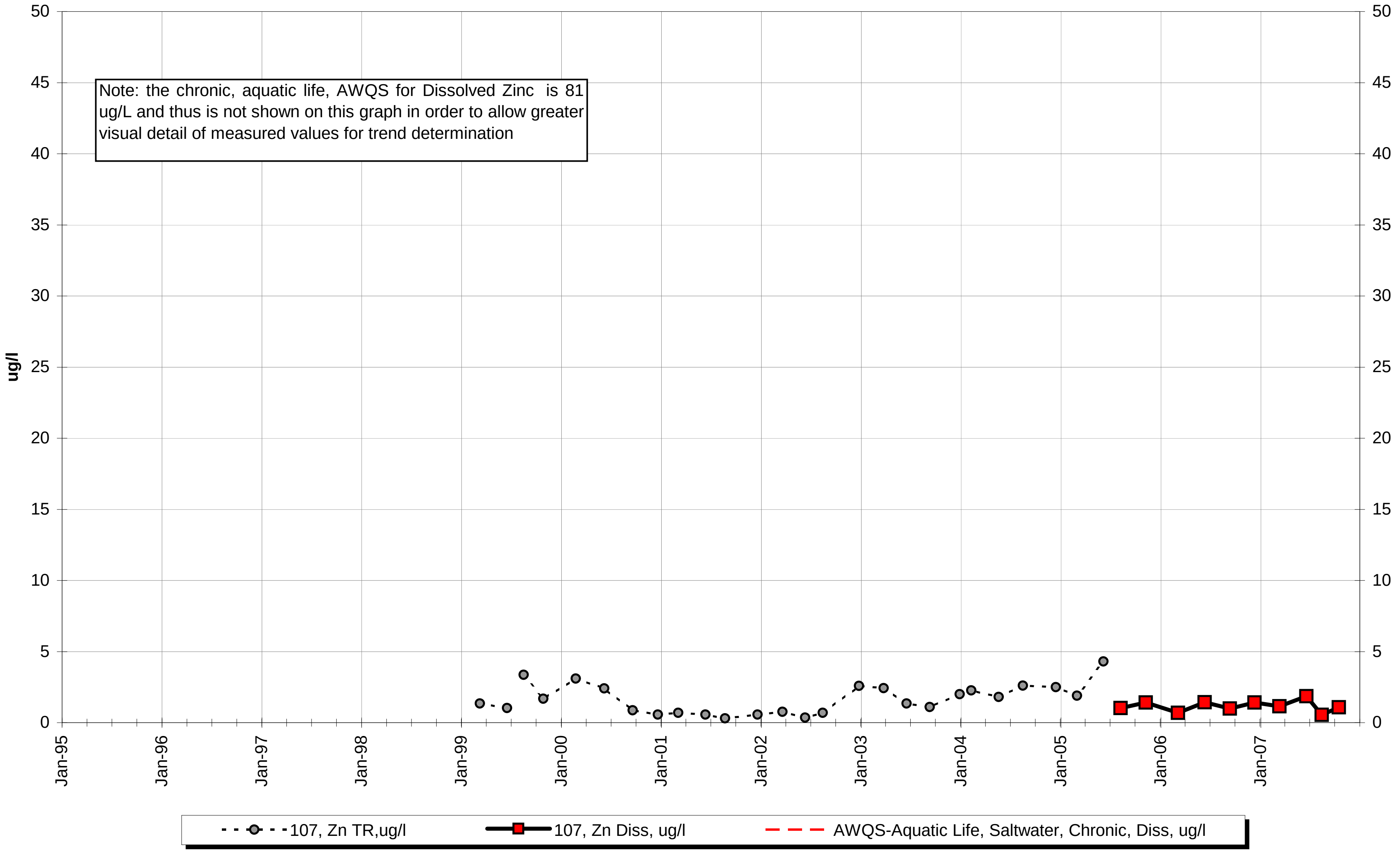
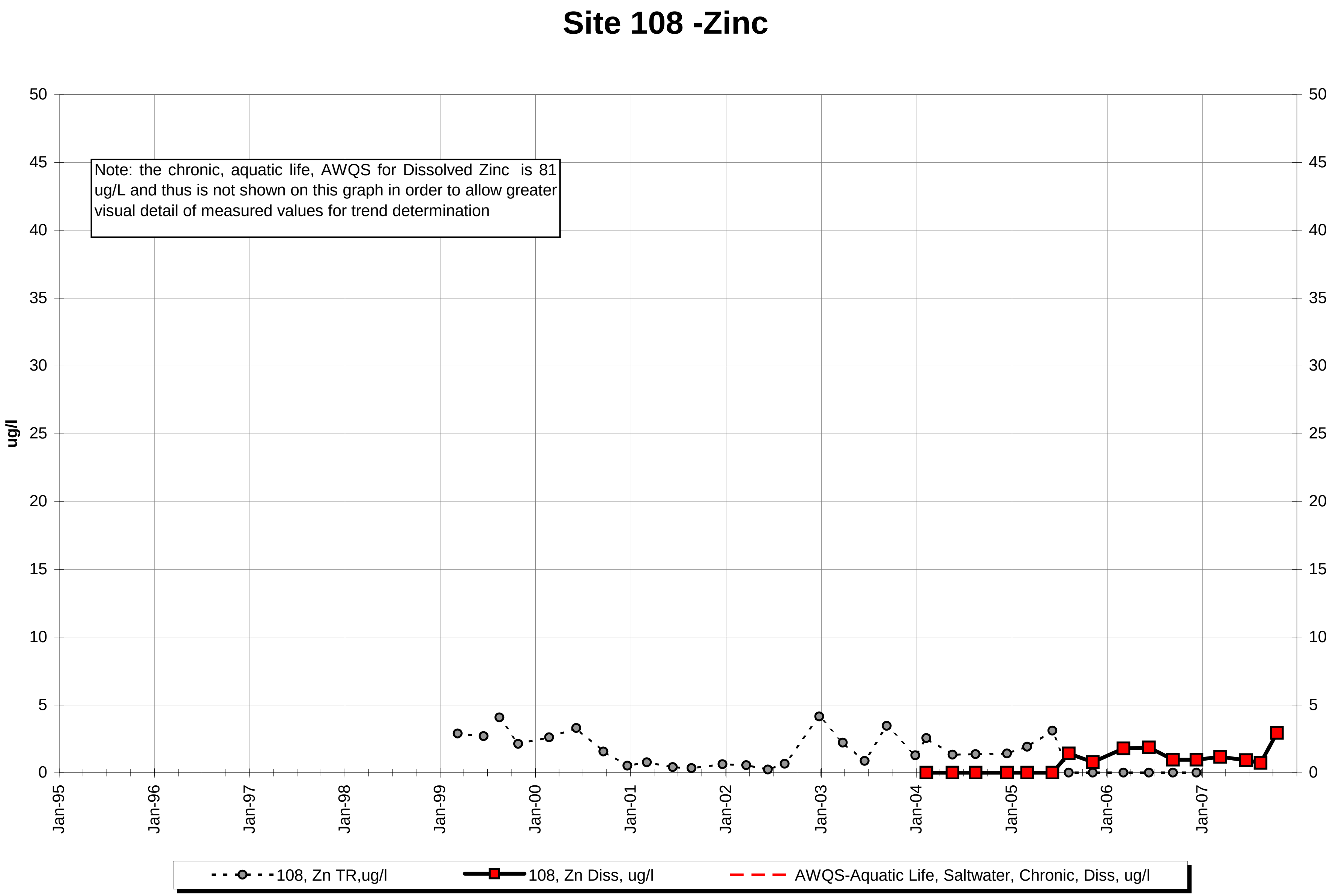


FIGURE 2-7c



Site 108 -Zinc
ug/l
50
45
40
35
30
25
20
15
10
5
0
Note: the chronic, aquatic life, AWQS for Dissolved Zinc is 81 ug/L and thus is not shown on this graph in order to allow greater visual detail of measured values for trend determination
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
108, Zn TR,ug/l
108, Zn Diss, ug/l
AWQS-Aquatic Life, Saltwater, Chronic, Diss, ug/l

FIGURE 3-1

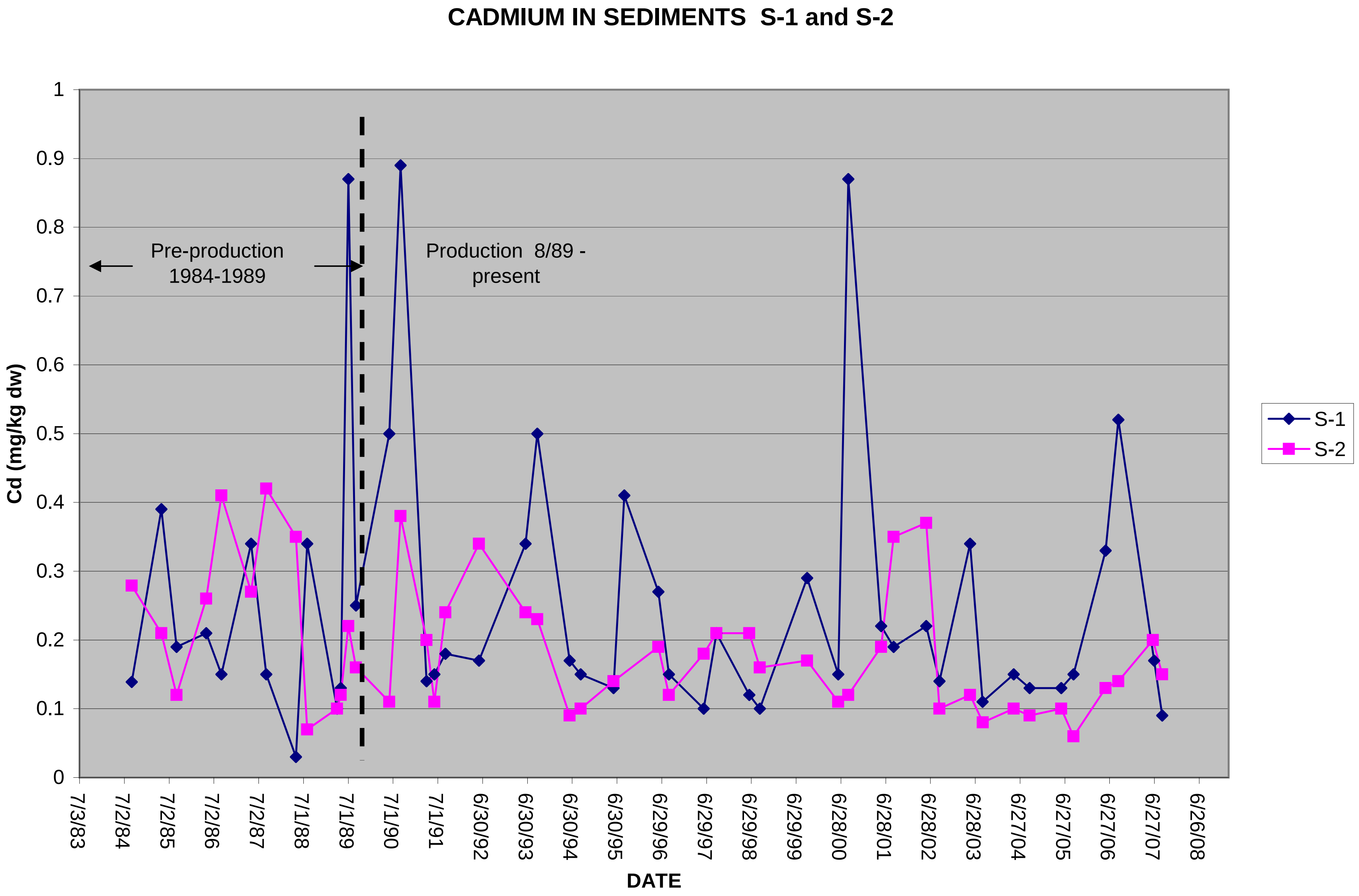

CADMIUM IN SEDIMENTS S-1 and S-2
Cd (mg/kg dw)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Pre-production
1984-1989
Production 8/89 -
present
S-1
S-2
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE

FIGURE 3-2

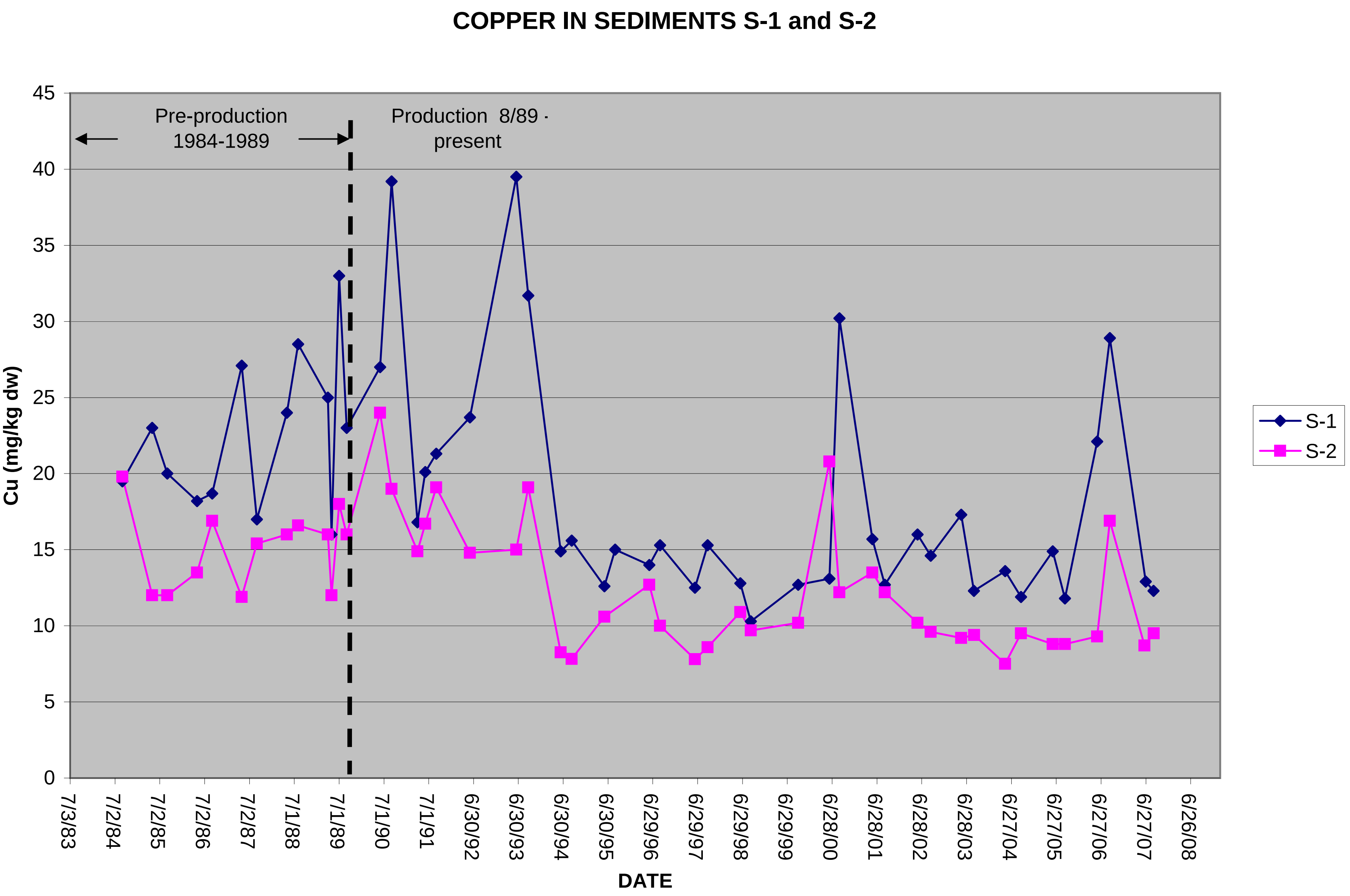

COPPER IN SEDIMENTS S-1 and S-2
Pre-production
1984-1989
Production 8/89 -
present
Cu (mg/kg dw)
45
40
35
30
25
20
15
10
5
0
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
S-1
S-2

FIGURE 3-3

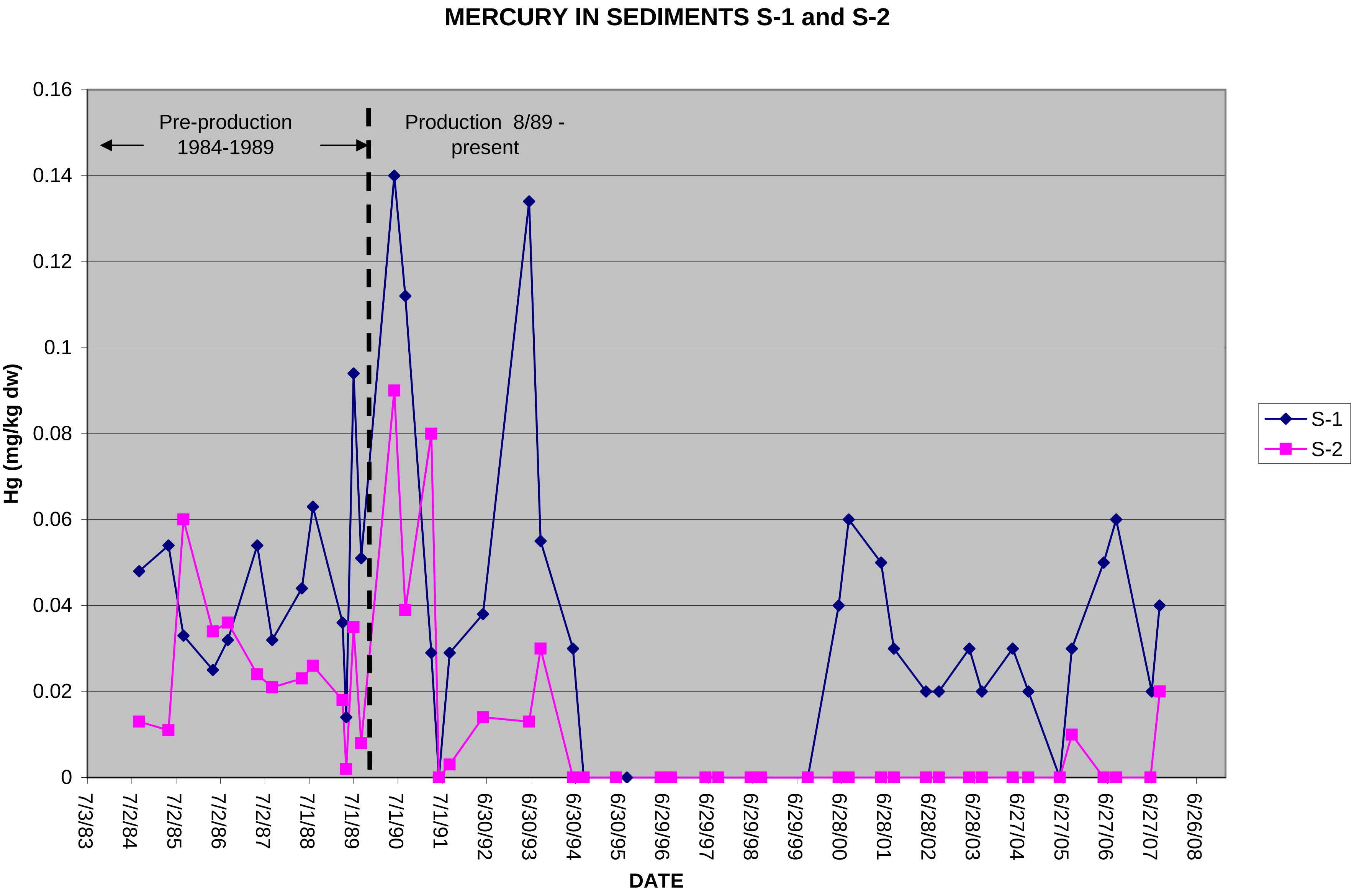

MERCURY IN SEDIMENTS S-1 and S-2
Hg (mg/kg dw)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Pre-production 1984-1989
Production 8/89 - present
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
S-1
S-2

FIGURE 3-4

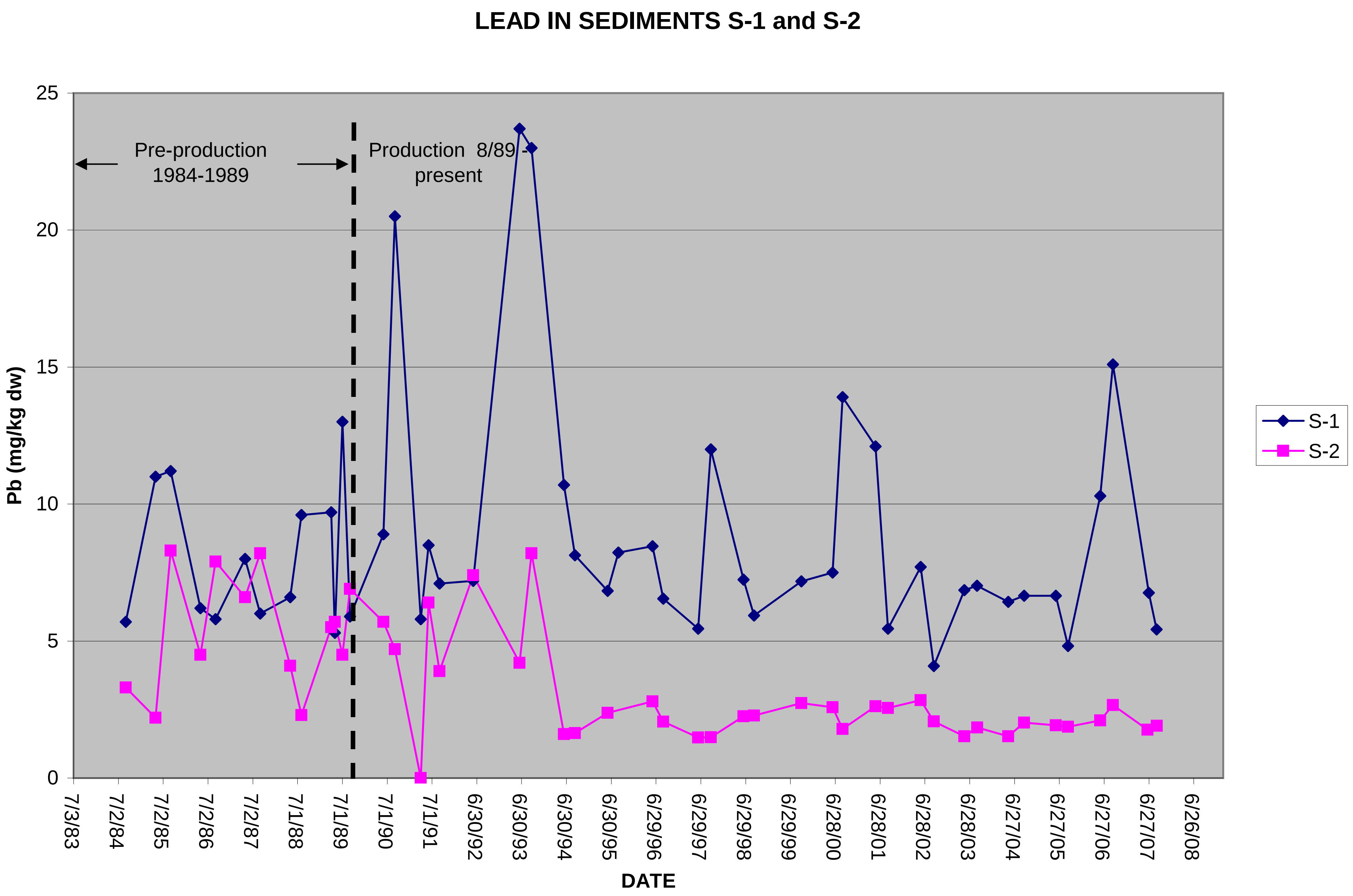

LEAD IN SEDIMENTS S-1 and S-2
Pb (mg/kg dw)
25
20
15
10
5
0
Pre-production
1984-1989
Production 8/89 -
present
S-1
S-2
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE

FIGURE 3-5

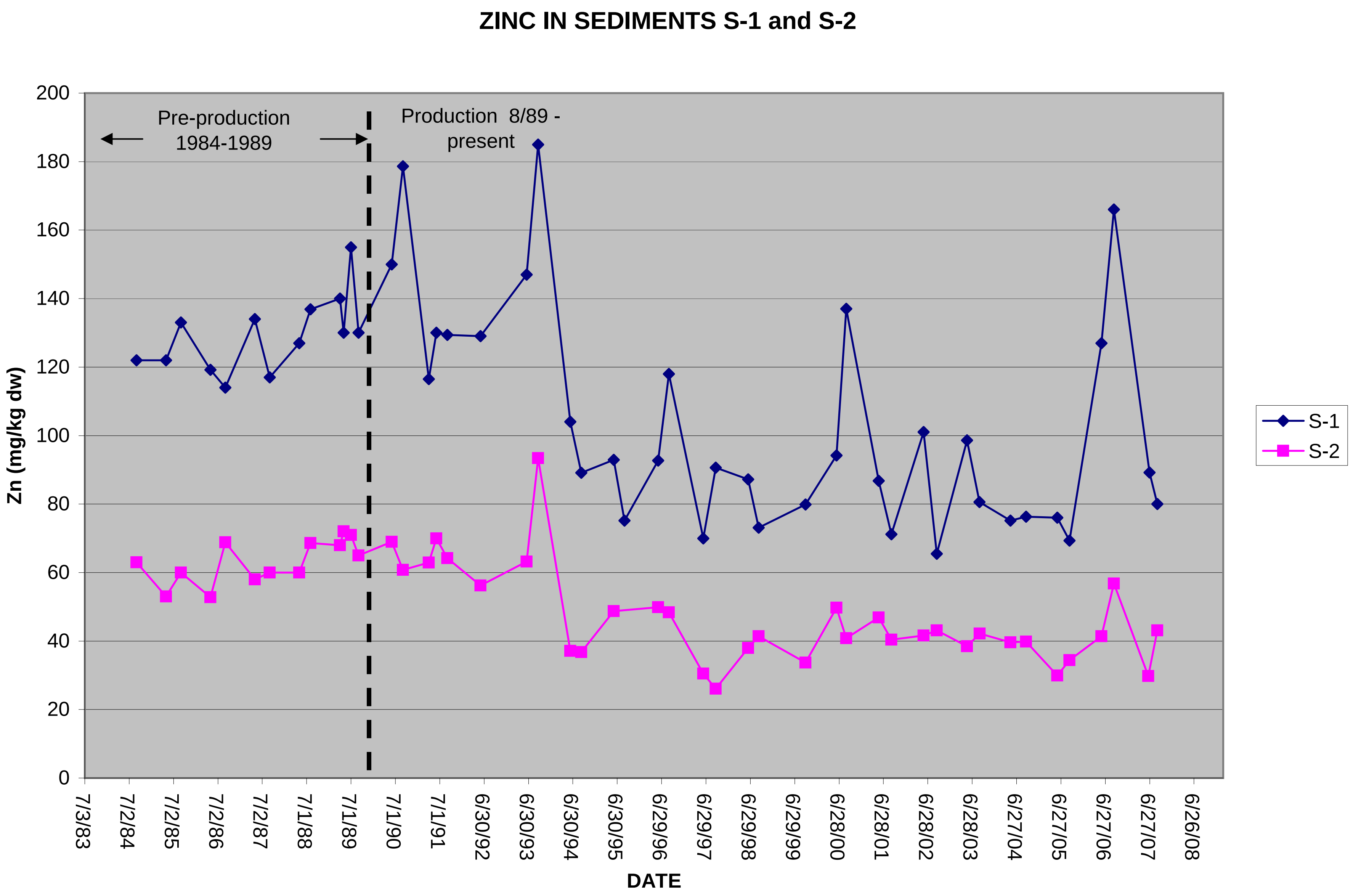

ZINC IN SEDIMENTS S-1 and S-2
Pre-production
1984-1989
Production 8/89 -
present
Zn (mg/kg dw)
0
20
40
60
80
100
120
140
160
180
200
DATE
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
S-1
S-2

FIGURE 3-6

CADMIUM IN SEDIMENT S-4, S-5S, S-5N

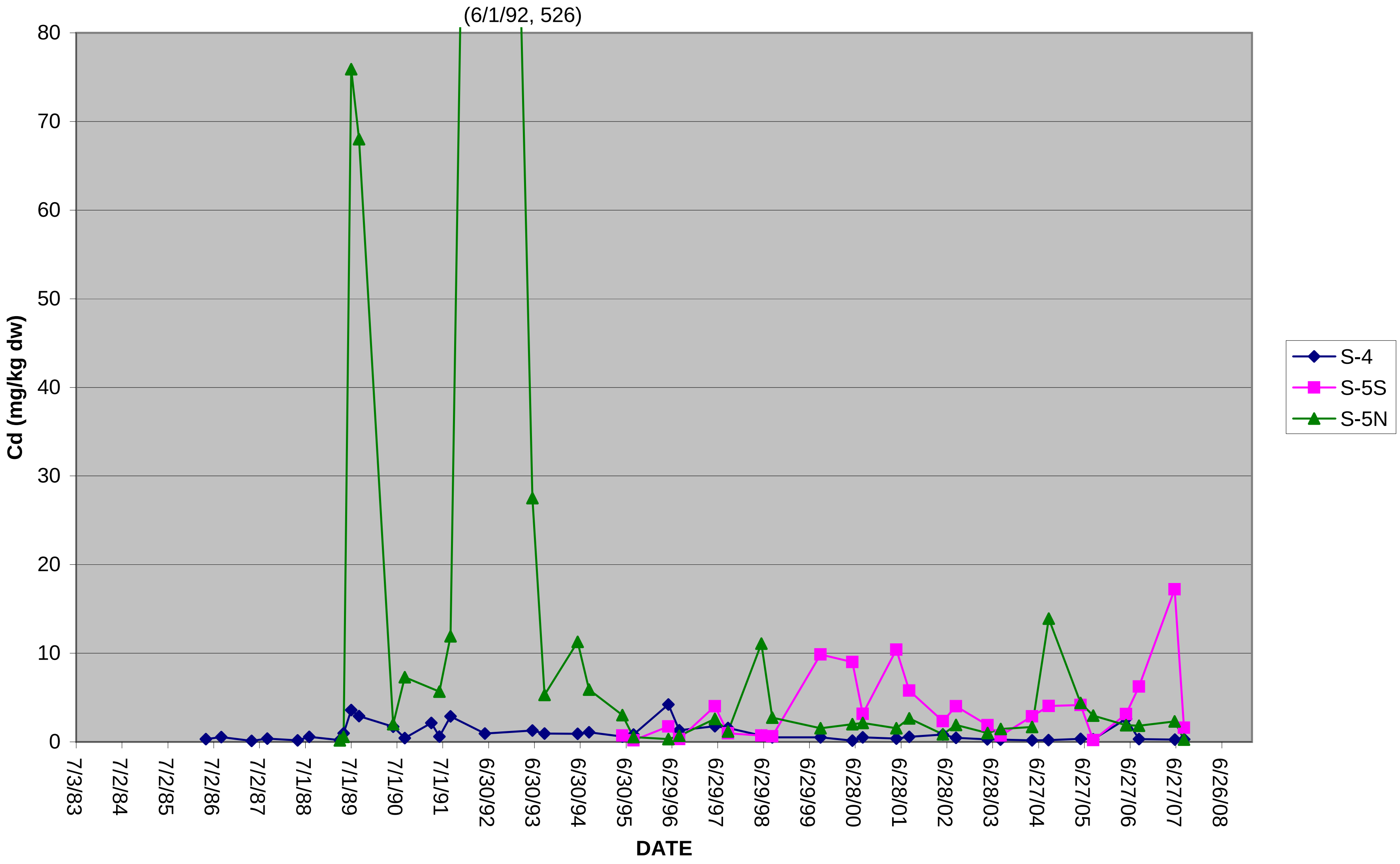


FIGURE 3-7

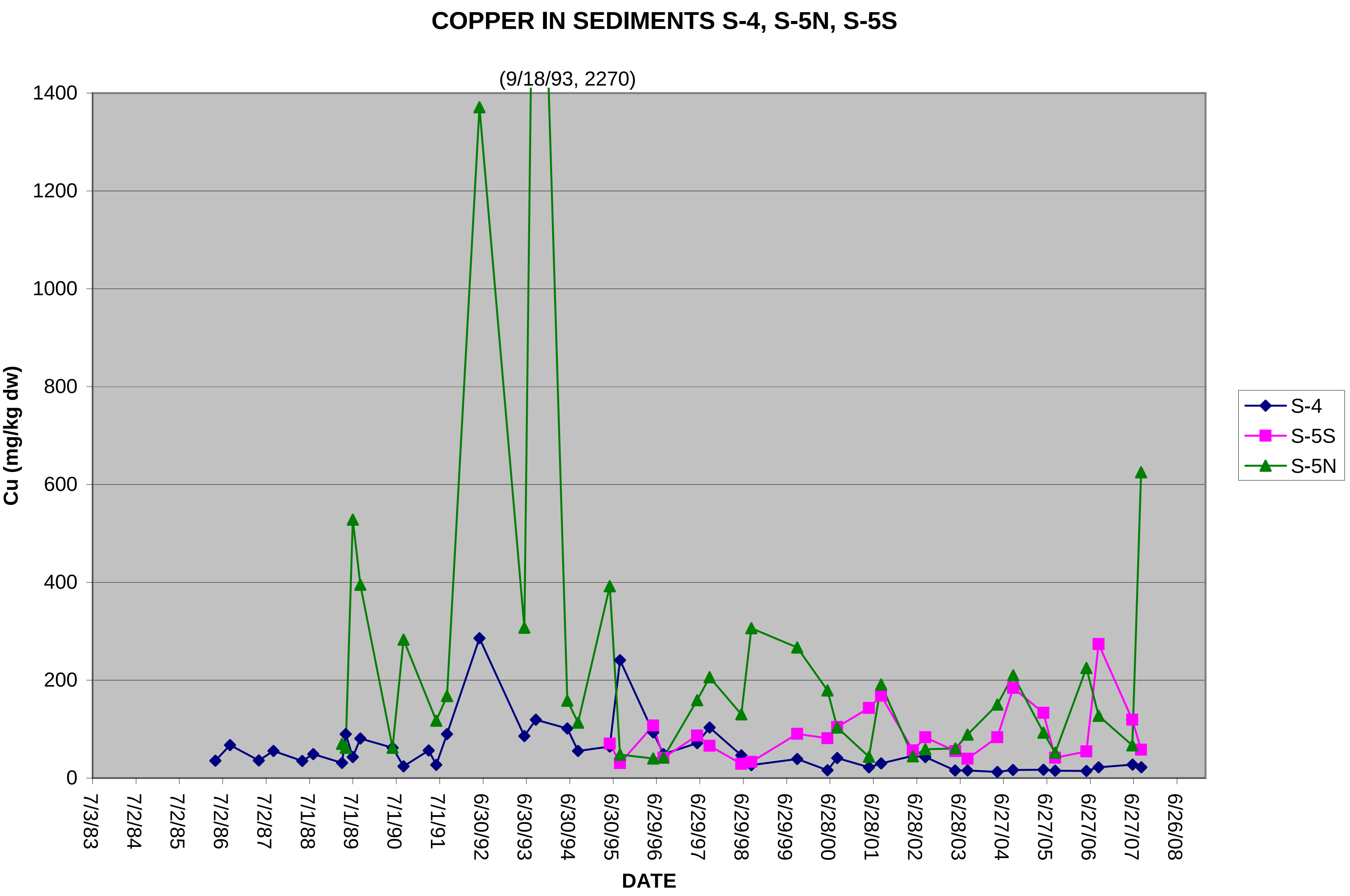

COPPER IN SEDIMENTS S-4, S-5N, S-5S
(9/18/93, 2270)
Cu (mg/kg dw)
1400
1200
1000
800
600
400
200
0
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
S-4
S-5S
S-5N

FIGURE 3-8

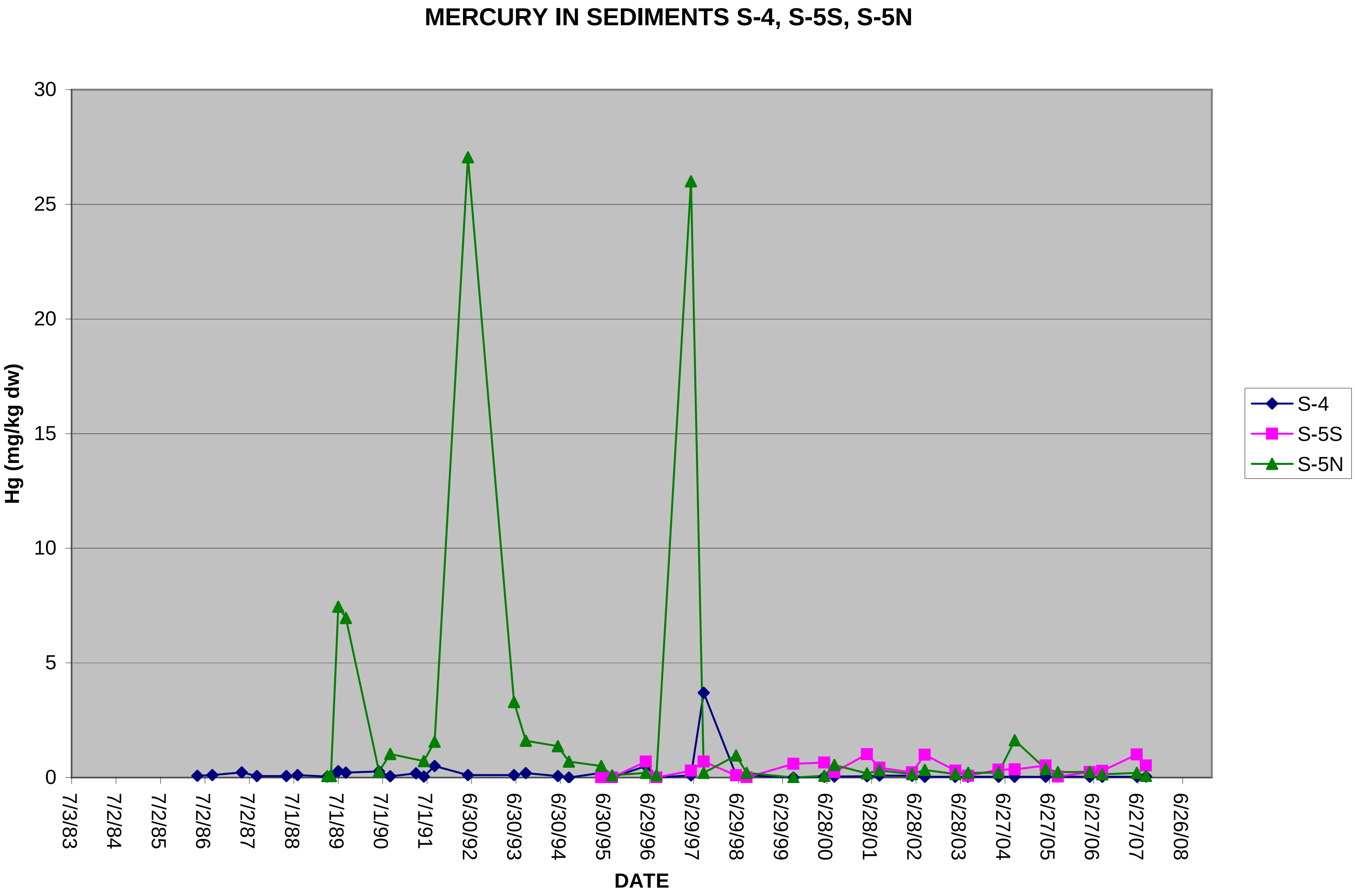

MERCURY IN SEDIMENTS S-4, S-5S, S-5N
Hg (mg/kg dw)
30
25
20
15
10
5
0
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
S-4
S-5S
S-5N

FIGURE 3-9

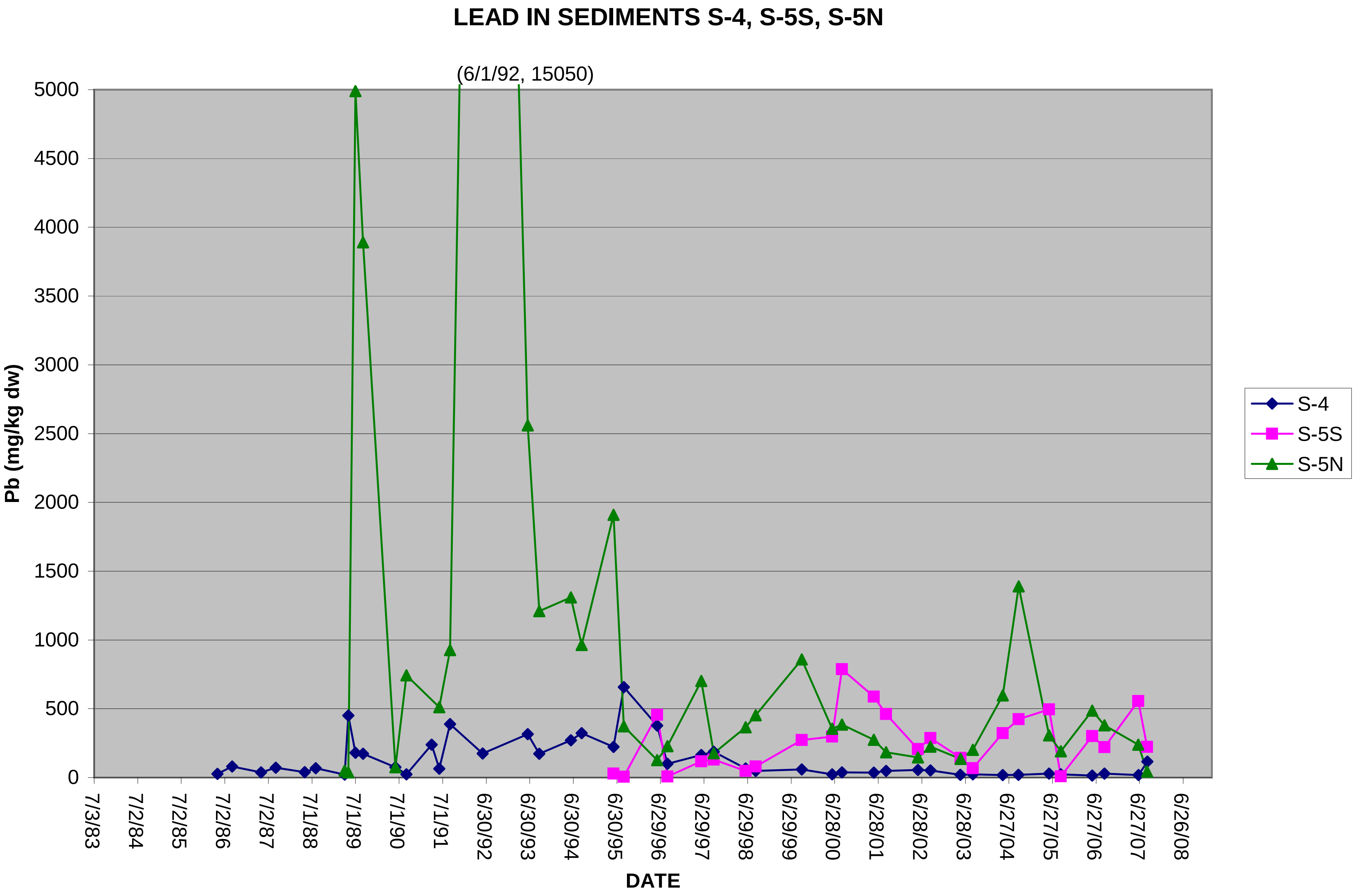

LEAD IN SEDIMENTS S-4, S-5S, S-5N
(6/1/92, 15050)
Pb (mg/kg dw)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
S-4
S-5S
S-5N

FIGURE 3-10

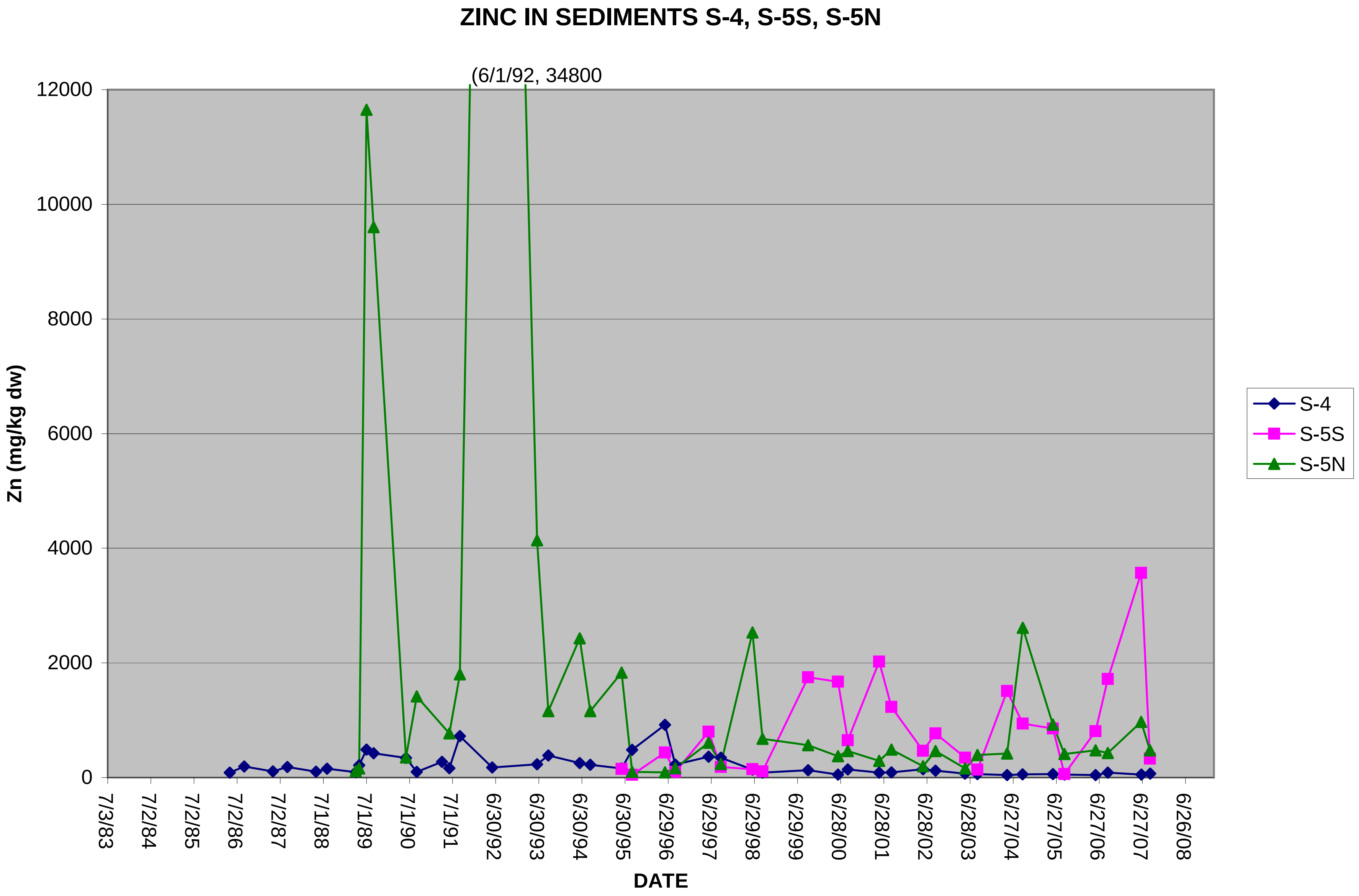

ZINC IN SEDIMENTS S-4, S-5S, S-5N
(6/1/92, 34800
12000
10000
8000
6000
4000
2000
0
Zn (mg/kg dw)
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
S-4
S-5S
S-5N

FIGURE 4-1

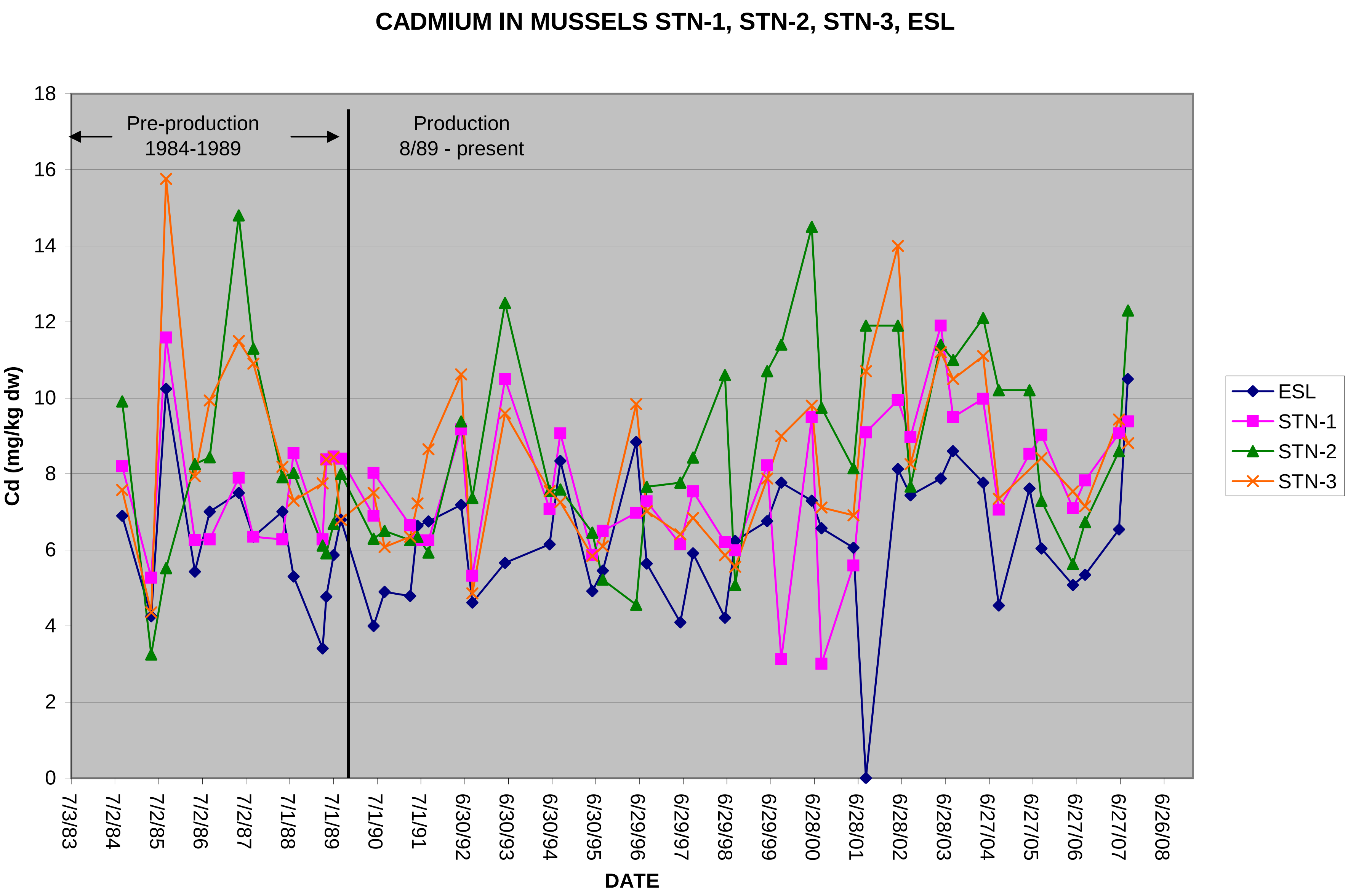
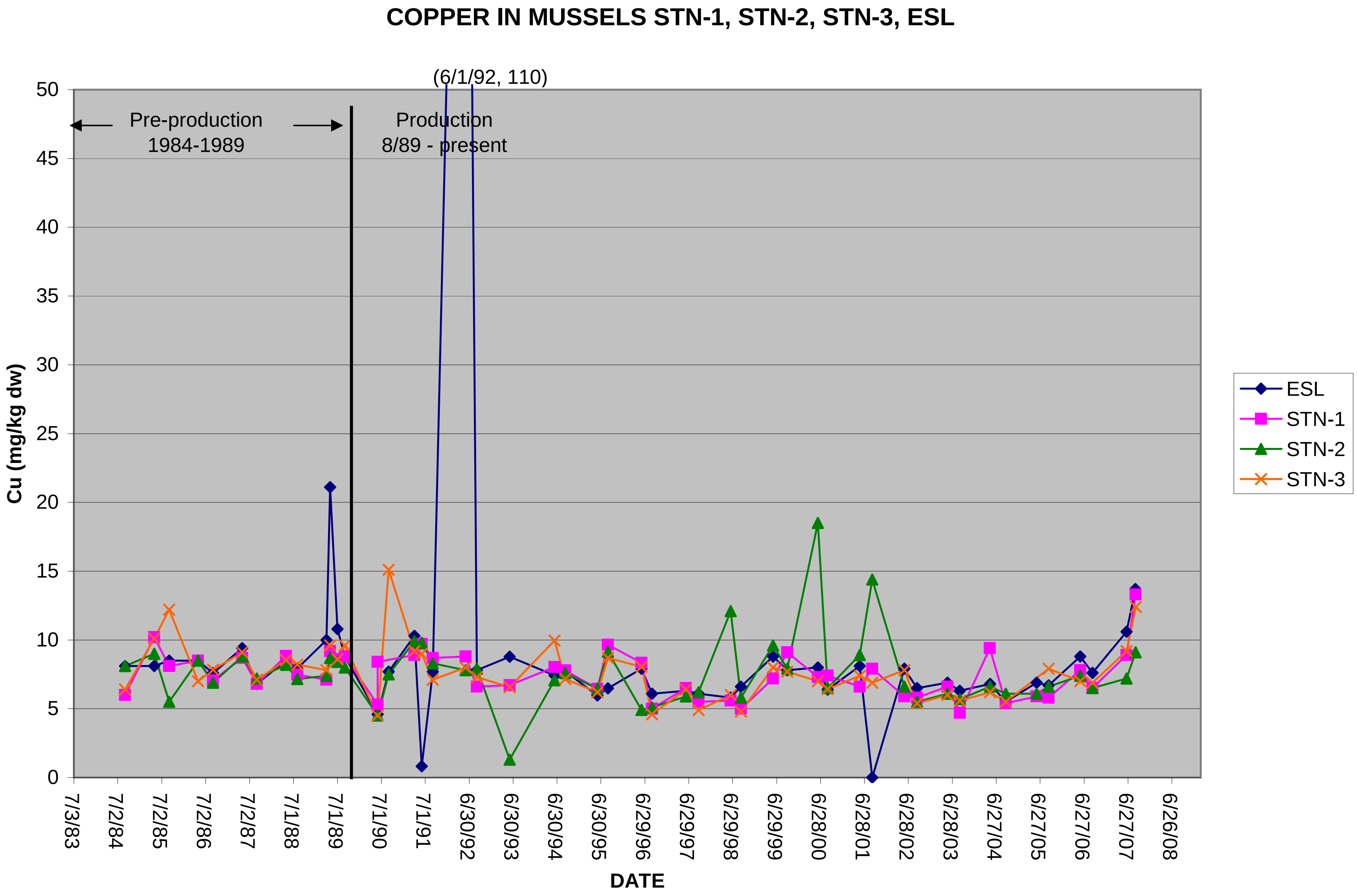
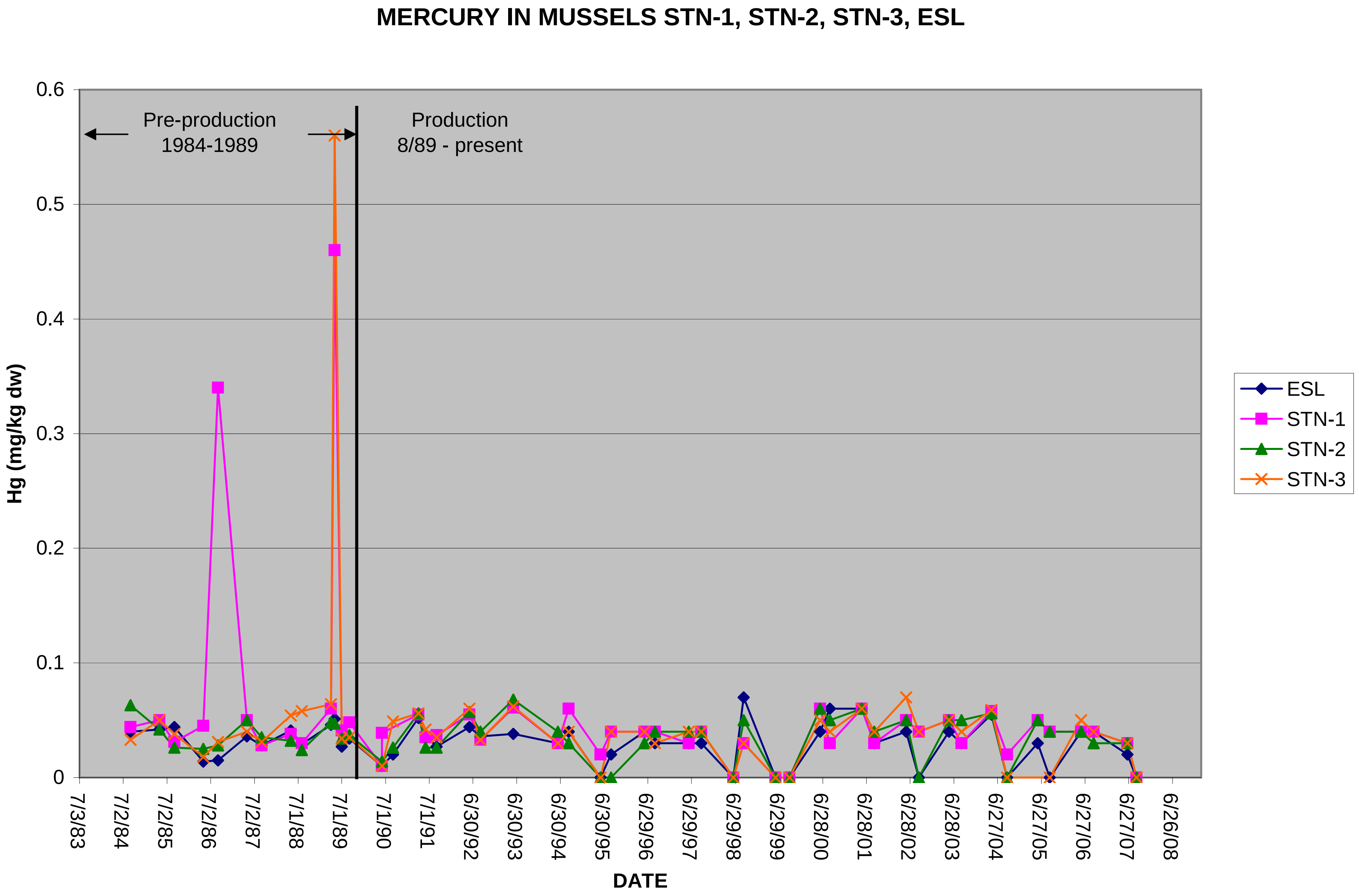

CADMIUM IN MUSSELS STN-1, STN-2, STN-3, ESL
Pre-production
1984-1989
Production
8/89 - present
Cd (mg/kg dw)
0
2
4
6
8
10
12
14
16
18
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
ESL
STN-1
STN-2
STN-3

FIGURE 4-2



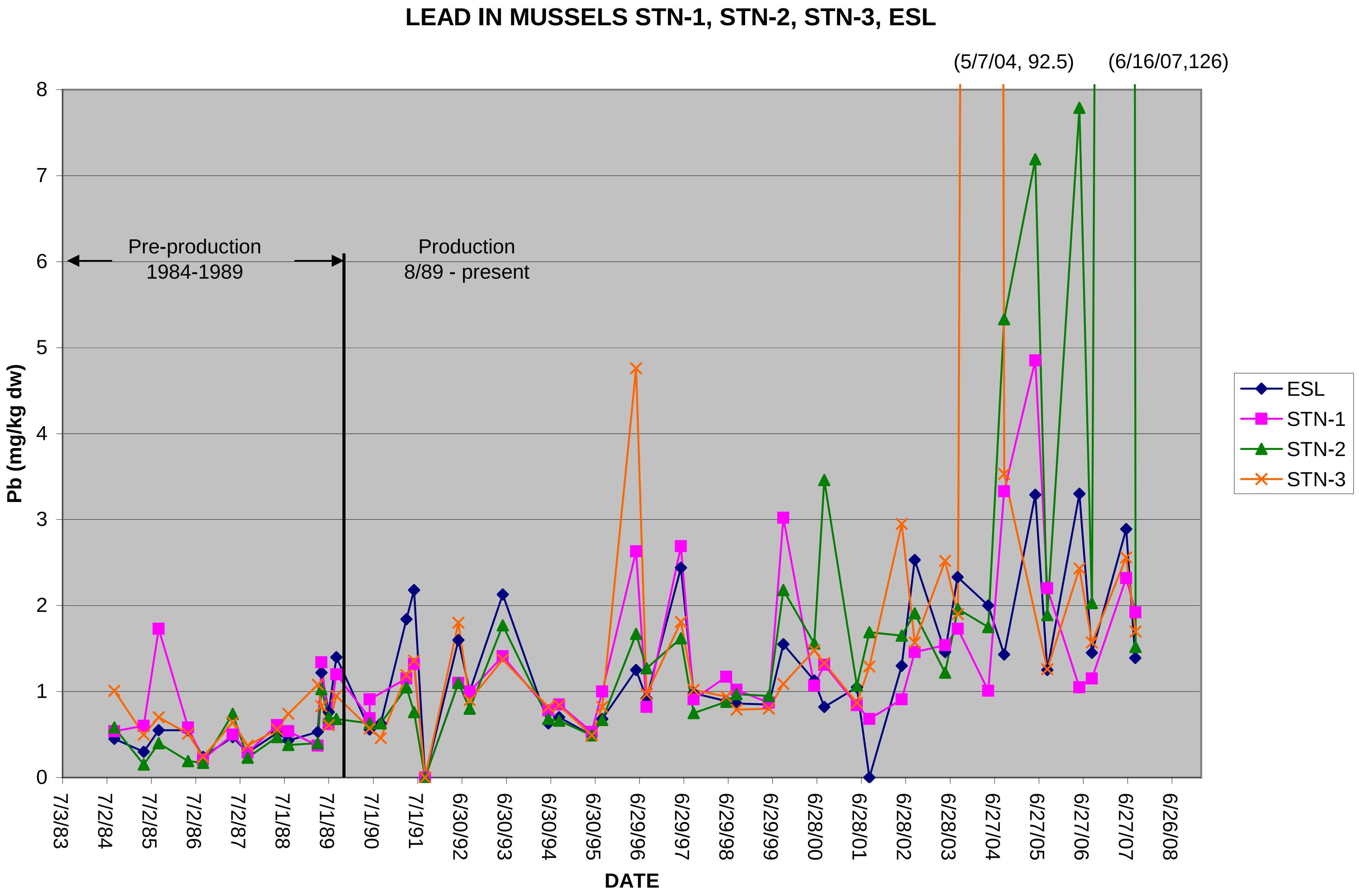
COPPER IN MUSSELS STN-1, STN-2, STN-3, ESL
(6/1/92, 110)
Pre-production
1984-1989
Production
8/89 - present
Cu (mg/kg dw)
50
45
40
35
30
25
20
15
10
5
0
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
ESL
STN-1
STN-2
STN-3

FIGURE 4-3



MERCURY IN MUSSELS STN-1, STN-2, STN-3, ESL
Hg (mg/kg dw)
0.6
0.5
0.4
0.3
0.2
0.1
0
Pre-production
1984-1989
Production
8/89 - present
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
ESL
STN-1
STN-2
STN-3

FIGURE 4-4



LEAD IN MUSSELS STN-1, STN-2, STN-3, ESL
(5/7/04, 92.5)
(6/16/07,126)
Pre-production
1984-1989
Production
8/89 - present
Pb (mg/kg dw)
0
1
2
3
4
5
6
7
8
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
ESL
STN-1
STN-2
STN-3

FIGURE 4-5

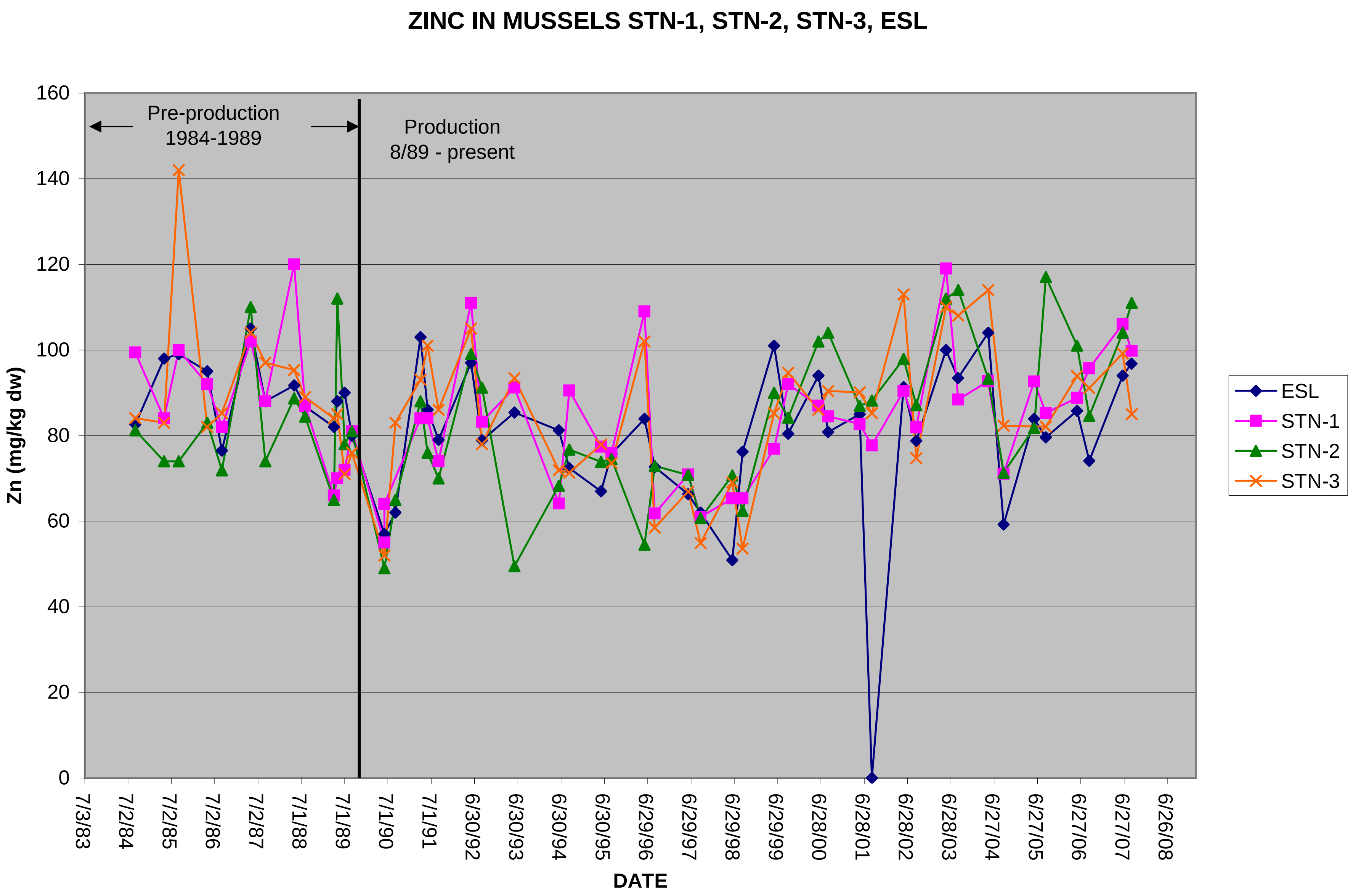

ZINC IN MUSSELS STN-1, STN-2, STN-3, ESL
Pre-production
1984-1989
Production
8/89 - present
Zn (mg/kg dw)
160
140
120
100
80
60
40
20
0
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
ESL
STN-1
STN-2
STN-3

FIGURE 4-6

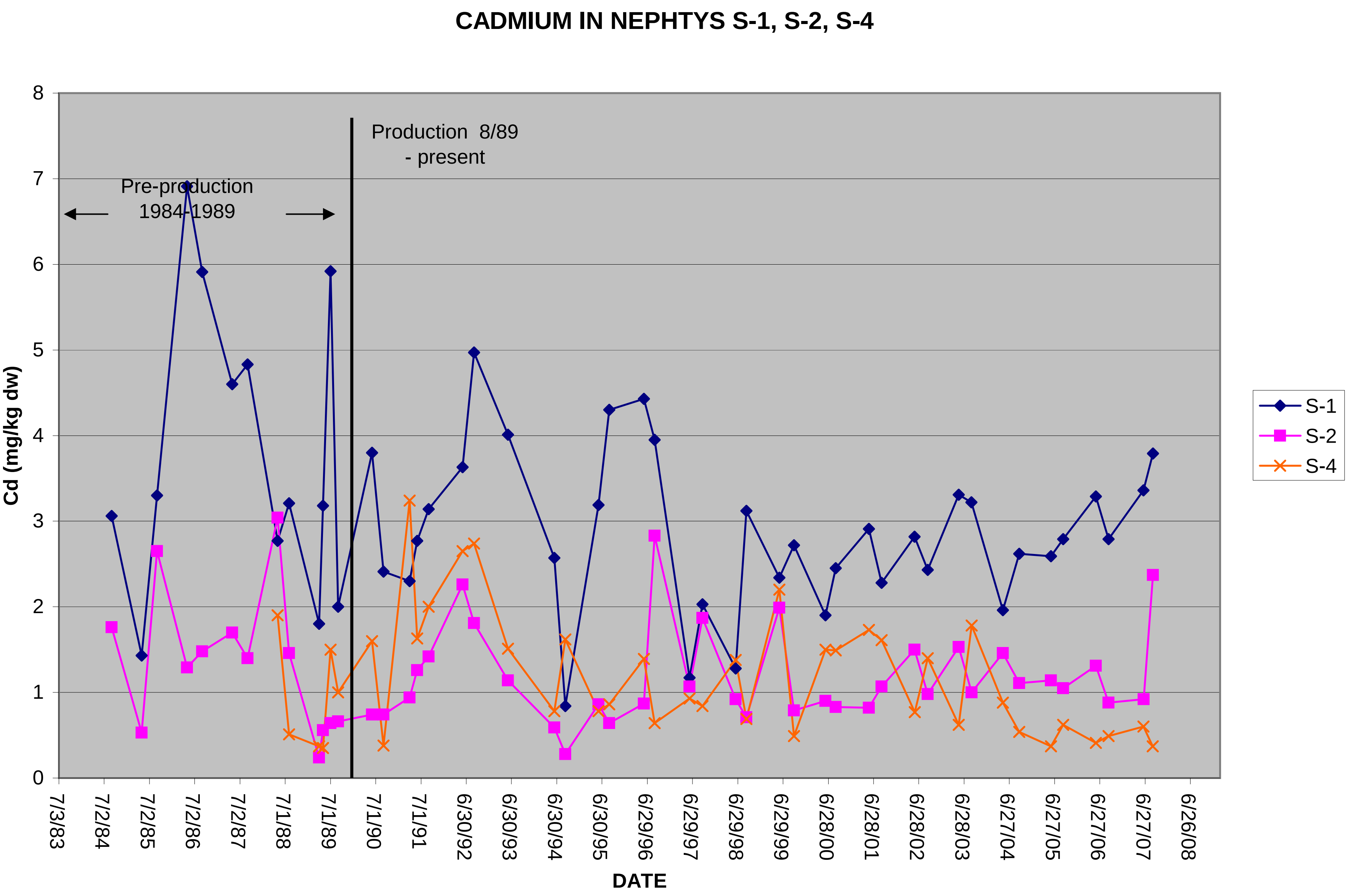

CADMIUM IN NEPHTYS S-1, S-2, S-4
Cd (mg/kg dw)
0
1
2
3
4
5
6
7
8
Pre-production
1984-1989
Production 8/89
- present
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
S-1
S-2
S-4

FIGURE 4-7

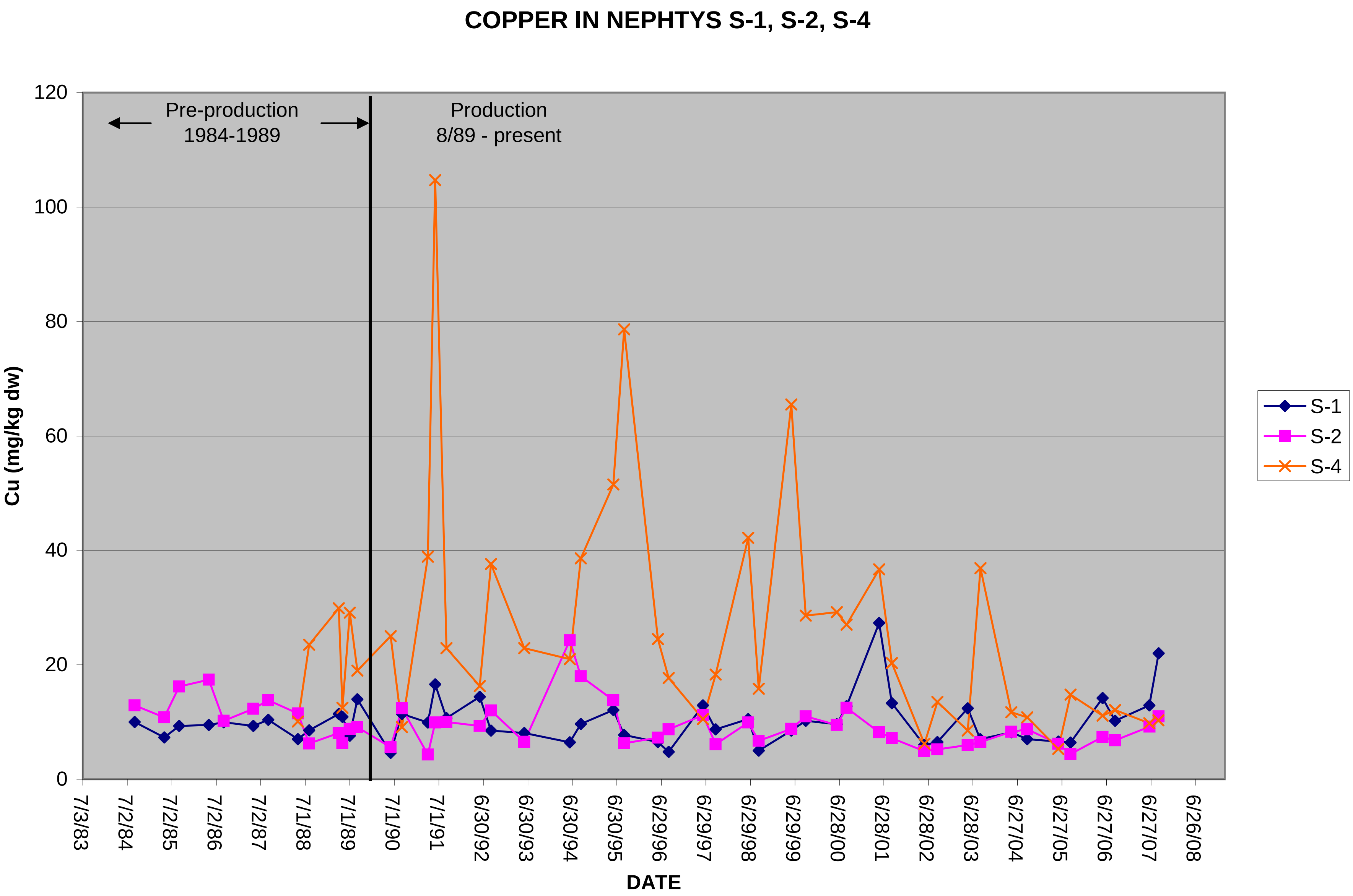

COPPER IN NEPHTYS S-1, S-2, S-4
Pre-production
1984-1989
Production
8/89 - present
Cu (mg/kg dw)
0
20
40
60
80
100
120
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
S-1
S-2
S-4

FIGURE 4-8

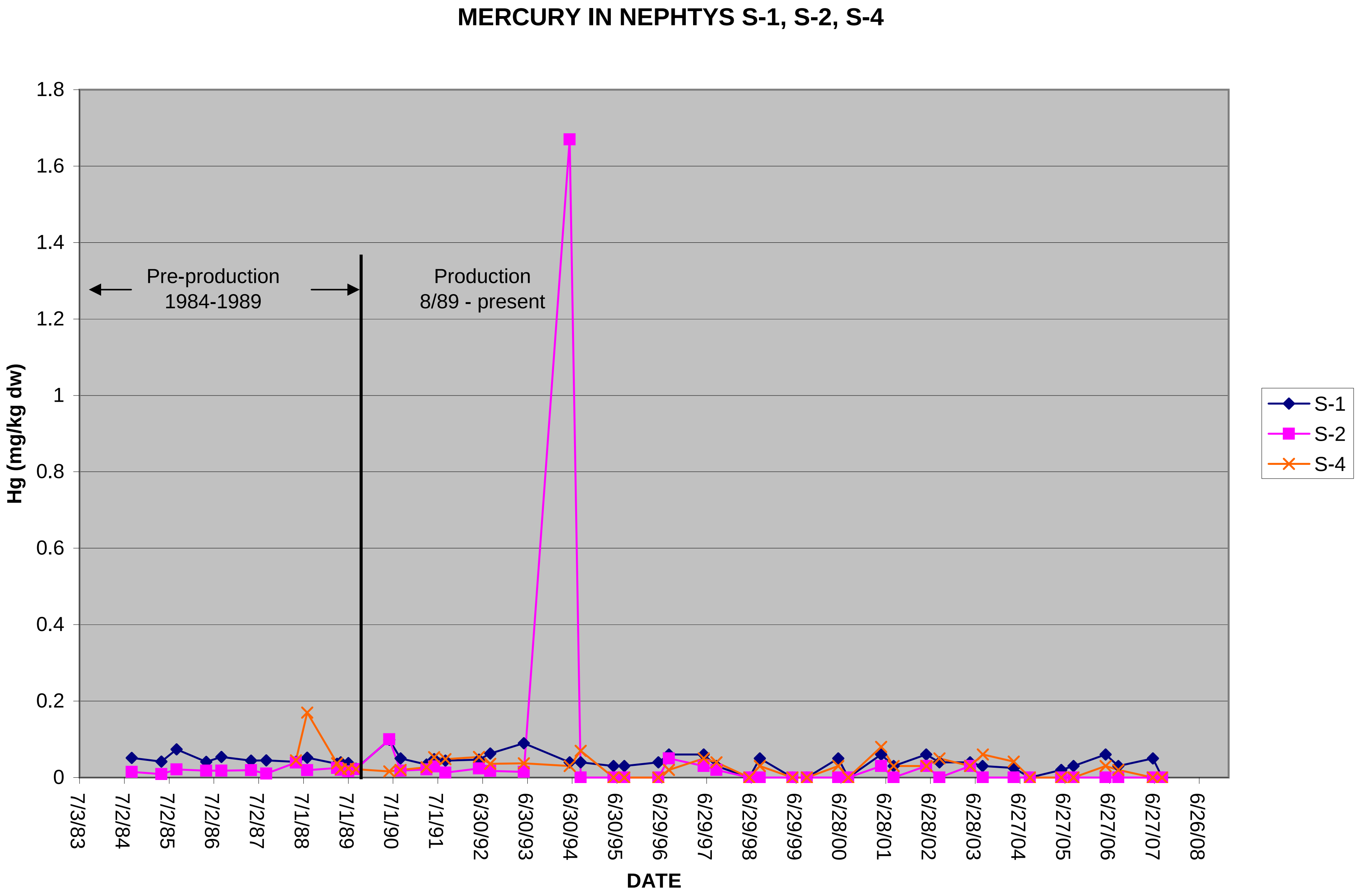

MERCURY IN NEPHTYS S-1, S-2, S-4
Hg (mg/kg dw)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Pre-production
1984-1989
Production
8/89 - present
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
S-1
S-2
S-4

FIGURE 4-9

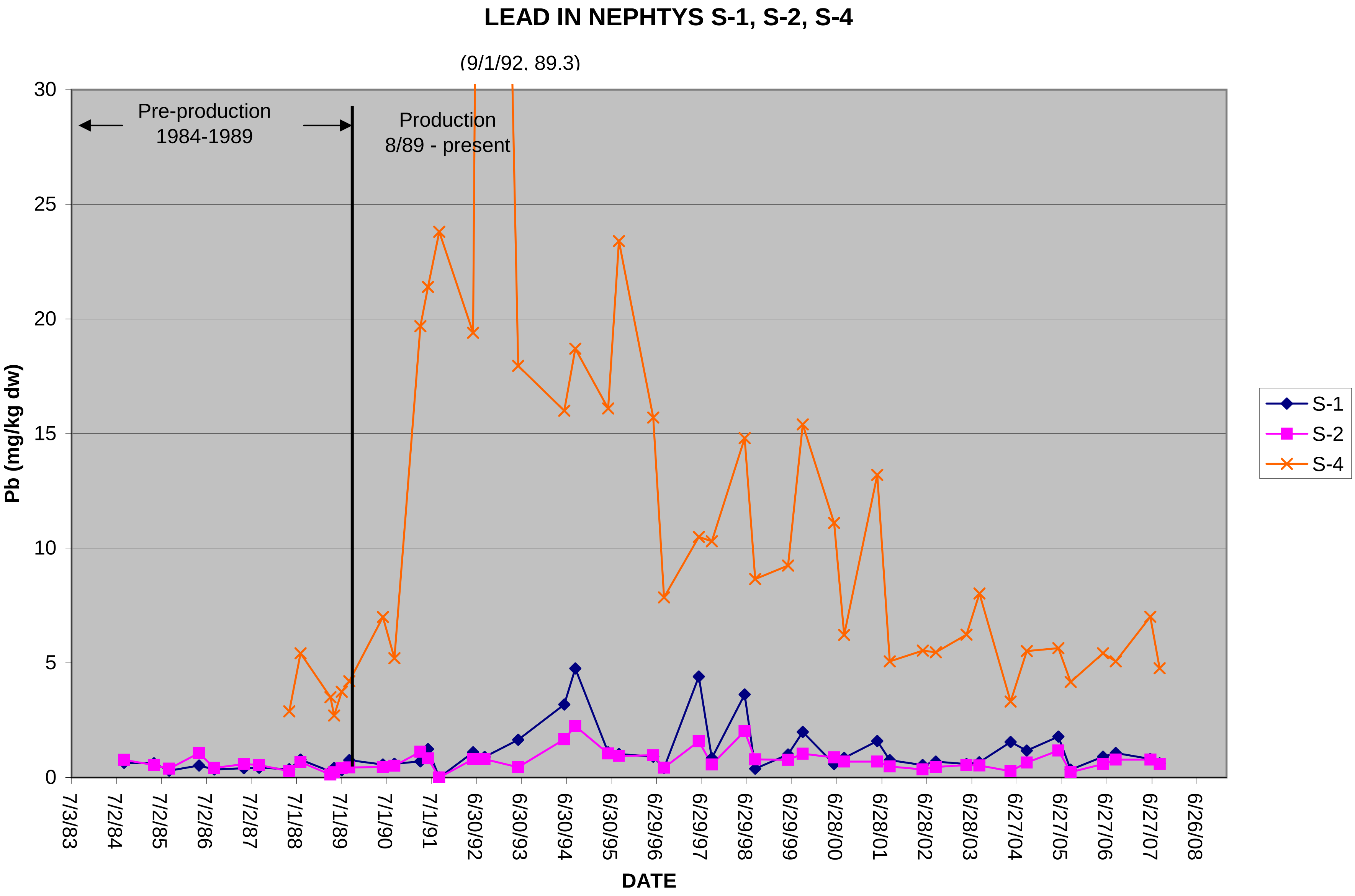
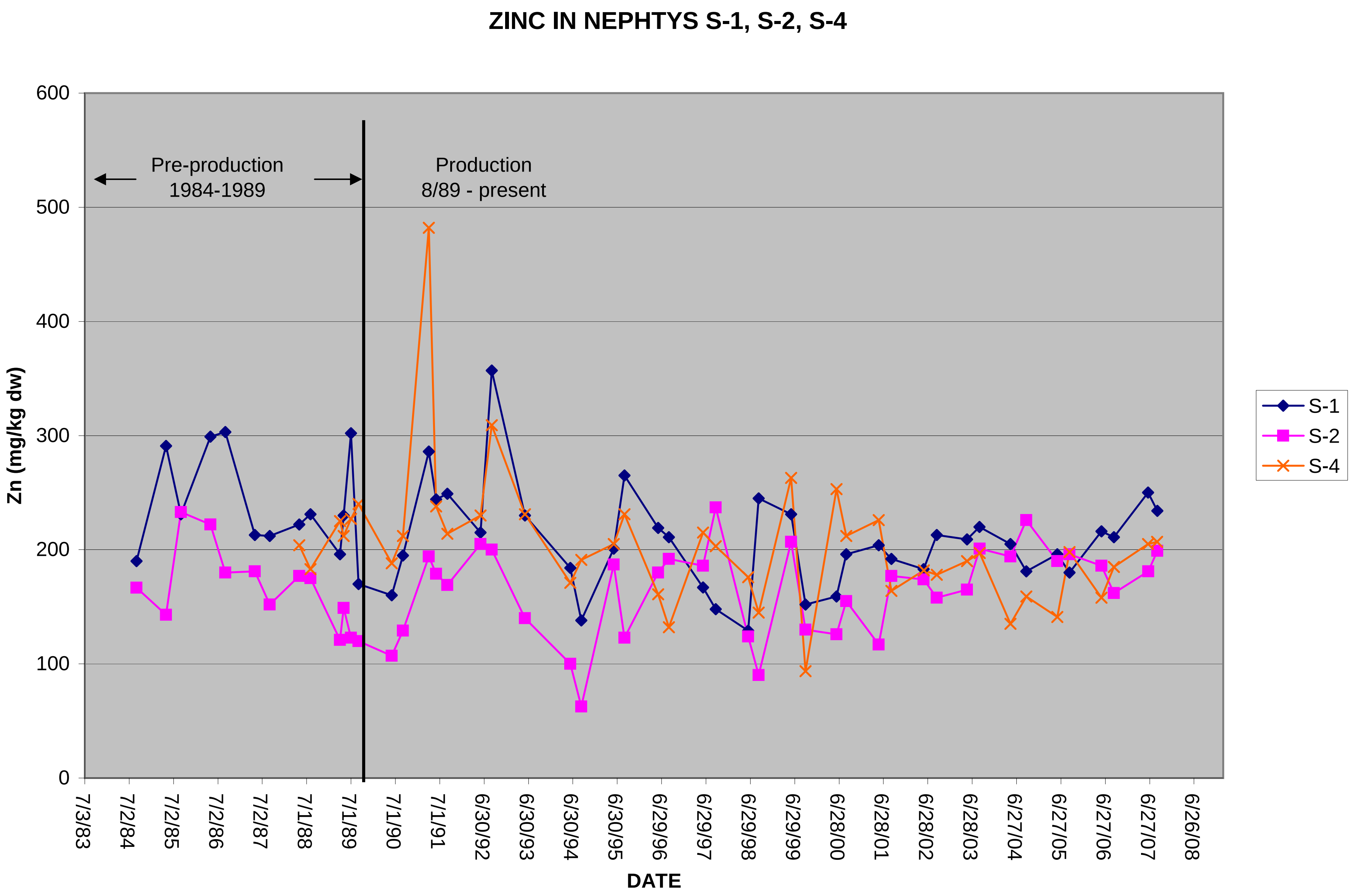

LEAD IN NEPHTYS S-1, S-2, S-4
(9/1/92, 89.3)
Pre-production
1984-1989
Production
8/89 - present
Pb (mg/kg dw)
0
5
10
15
20
25
30
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
S-1
S-2
S-4

FIGURE 4-10


ZINC IN NEPHTYS S-1, S-2, S-4
Zn (mg/kg dw)
0
100
200
300
400
500
600
Pre-production
1984-1989
Production
8/89 - present
7/3/83
7/2/84
7/2/85
7/2/86
7/2/87
7/1/88
7/1/89
7/1/90
7/1/91
6/30/92
6/30/93
6/30/94
6/30/95
6/29/96
6/29/97
6/29/98
6/29/99
6/28/00
6/28/01
6/28/02
6/28/03
6/27/04
6/27/05
6/27/06
6/27/07
6/26/08
DATE
S-1
S-2
S-4

MARTIN MARIETTA

Environmental
Center

FINAL RESULTS OF THE 1981 FIELD PROGRAM FOR THE GREENS CREEK PROJECT

PART I -- HAWK INLET AND YOUNG BAY

Environmental Center
Martin Marietta Corporation
1450 South Rolling Road
Baltimore, Maryland 21228

October 1981

FINAL RESULTS OF THE
1981 FIELD PROGRAM
FOR THE GREENS CREEK PROJECT

PART I -- HAWK INLET AND YOUNG BAY

A. F. Holland

M. Hiegel and W. Richkus

Environmental Center
Martin Marietta Corporation
1450 South Rolling Road
Baltimore, Maryland 21228

Approval for Release:

William A. Richkus
Technical Director

T. T. Polgar
Associate Director

October 1981

FOREWORD

This report is based on findings of field studies carried out by the Martin Marietta Environmental Center under contract to Noranda Mining, Inc.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION

Noranda Mining, Inc., is currently developing a mine in the Greens Creek area of Admiralty Island in southeastern Alaska. A former cannery site, located on Hawk Inlet near Greens Creek, will be the site of facilities to be used in loading ore concentrate into transport vessels and unloading supplies for the mining operation.

Studies of the aquatic biology of Hawk Inlet have been conducted over the past 3 years to assess potential impacts of the mining operation (Noranda Exploration, Inc., 1978; IEC, 1980). To provide a basis for establishing preoperational and baseline conditions, these studies were augmented with investigations of soft-bottom benthic organisms and sediments in Hawk Inlet (conducted from 8 July to 14 July 1981). Additional work on the soft-bottom benthos was performed in Young Bay, which is the proposed location of docking facilities for transporting personnel and supplies to the mine site.

Several different, but related, studies were conducted for baseline characterization of benthic communities, habitats, and heavy metals tissue levels:

- Replicated quantitative samples of benthic organisms were taken in: (1) intertidal and subtidal soft-bottom habitats in Young Bay near the vicinity of the proposed docking facility, (2) in similar habitats north and south of the location of the proposed docking facility, (3) at the cannery, (4) at the head of Hawk Inlet, and (5) at the Greens Creek delta near the mouth of Hawk Inlet.

- Sediment samples were taken and environmental variables measured at all sampling locations. Sediment samples were analyzed for physical properties, metal levels, hydrocarbons, and oil and grease.

- Three species of invertebrates (*Mya arenaria*, *Mytilus edulis*, and an unidentified starfish species, probably *Pisaster ochraceus* were collected at the cannery and analyzed for heavy metals tissue concentrations.

- Tissue samples of fish from a Zinc Creek tributary under consideration as a tailings pond site were analyzed for heavy metals concentrations (these data are presented in Appendix A).

Surveys of epifaunal benthos organisms inhabiting hard surfaces in Hawk Inlet were conducted previously and were not duplicated here (Noranda Exploration, Inc., 1978; IEC, 1980). Qualitative samples of epifaunal organisms were collected from Young Bay.

II. METHODS

A. BIOLOGICAL FIELD METHODS

A field survey was conducted from 8-14 July 1981 to quantitatively sample benthic macroinvertebrates in representative soft-bottom subtidal and intertidal habitats in Hawk Inlet and Young Bay (Fig. 1). Table 1 summarizes information on the depth of sampling locations, sampling gear used, area sampled, and number of replicate samples collected at each sampling station. Three stations at each study area were located in intertidal areas and three stations were located in subtidal areas. All intertidal stations were located in the mid-littoral zone characterized by epifaunal populations of Fucus disticus (brown algae), Mytilus edulis (mussel), and Balanus glandula (barnacles).

Quantitative data on major soft-bottom habitat types in regions likely to be developed were obtained by sampling at various stations in Hawk Inlet. Stations and habitats sampled were:

- One intertidal and one subtidal station located in the area of the Greens Creek delta -- sandy/gravel riverine delta
- One intertidal station located at the cannery -- sandy intertidal region
- One subtidal station located at the cannery -- soft muddy bottom
- One intertidal and one subtidal station at the head of the inlet -- muddy-sand tidal flat.

At Young Bay, two benthic stations (1 intertidal, 1 subtidal) were sampled at the site proposed as a docking facility, and two benthic stations (1 intertidal and 1 subtidal) were sampled at sites located north and south of the proposed docking facility.

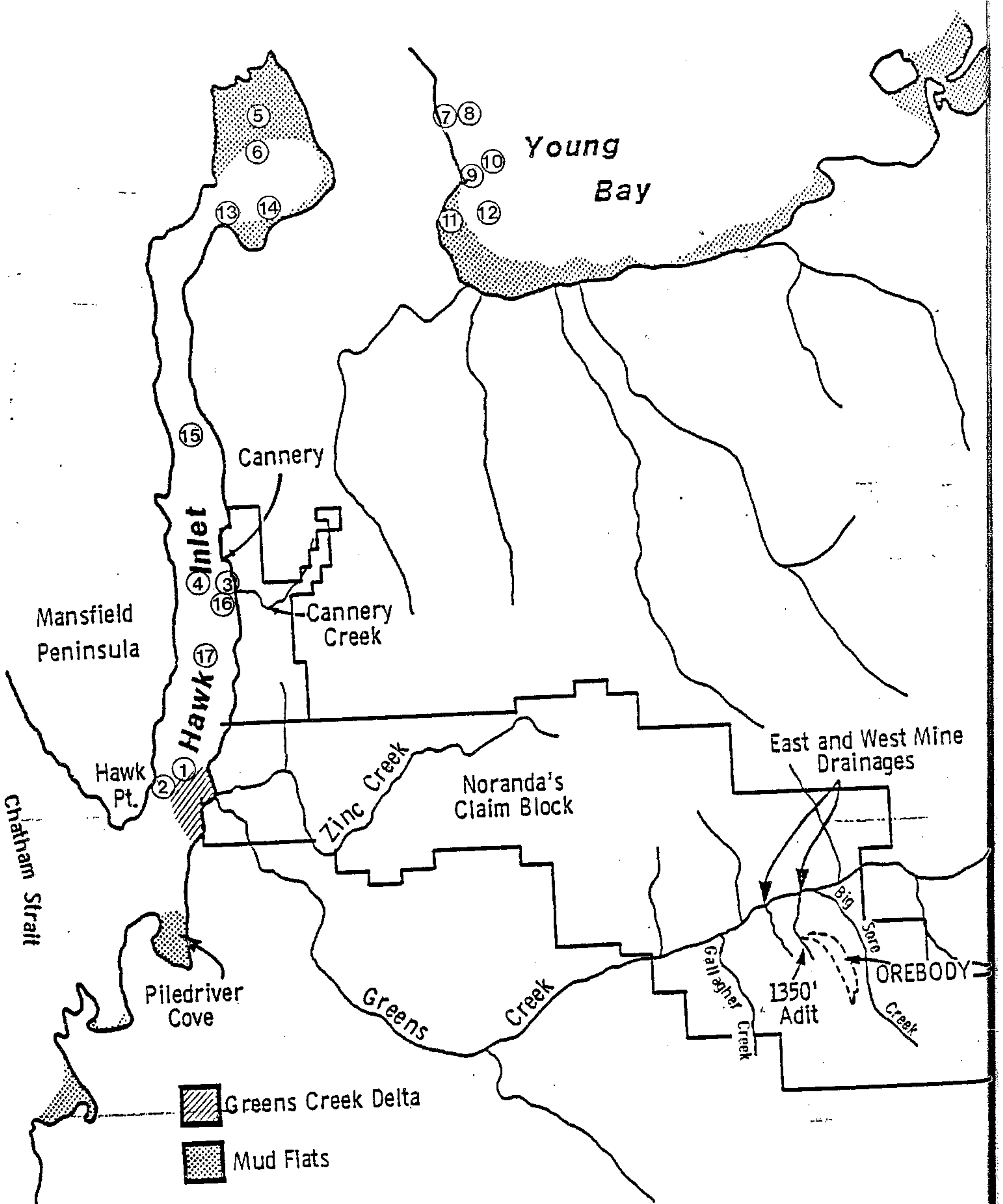


Figure 1. Map showing area where benthic sampling was conducted in July 1981

Table 1. Summary of sampling information for study sites. The sediment depth of all samples was approximately 15 cm.

Study Site	Station Location	Depth	Sampling Gear	Area Sampled	Number of Replicates Collected
Hawk Inlet	Greens Creek Delta	Intertidal	Hand core	77 cm^2	5
		8m	Ponar grab	262 cm^2	5
	Cannery	Intertidal	Hand core	153 cm^2	5
		63m	Ponar grab	262 cm^2	5
	Head of Inlet	Intertidal	Hand core	77 cm^2	5
		5m	Ponar grab	262 cm^2	5
Young Bay	Northern Reference	Intertidal	Hand core	100 cm^2	4
		3m	Hand core	77 cm^2	4
	Dock Site	Intertidal	Hand core	100 cm^2	4
		3m	Hand core	77 cm^2	4
	Southern Reference	Intertidal	Hand core	100 cm^2	4
		3m	Hand core	77 cm^2	4

The latter sites are referred to hereafter as reference areas since they were far enough removed from the proposed docking facility to be unaffected by its construction or operations. The physical appearance and environmental setting of the beach at the northern reference area were similar to the proposed dock site, while the beach at the southern reference area was more protected from wave action and appeared to contain less large-sized cobble and rocks. However, sand and other sediments under the cobble appeared similar to that at the proposed docking facility. Subtidal stations were established in sandy nearshore substrates that occurred throughout this region of Young Bay; all appeared to be relatively similar.

All biological samples were sieved shortly after collection through a 0.5-mm screen using an elutriative process. Materials retained on the screen were fixed in a 10% formalin-rose bengal solution at the cannery and transported back to Baltimore for sorting in the laboratory. During laboratory processing, all invertebrates collected were identified to the lowest practical taxonomic level and counted. A reference collection of the species observed is being maintained in Baltimore. Identifications have been verified by recognized experts at the National Museum of Canada and the Smithsonian Institute.

A sediment sample was collected along with the biological samples at each station for determination of mechanical properties, carbon content, and sediment burdens of metals and hydrocarbons. These sediment properties generally are related to the kinds and relative abundances of benthic species in soft-bottom habitats. Additional sediment samples, collected at locations in Hawk Inlet where the biota were not sampled (Fig. 1), served to establish the extent of various bottom types in subtidal habitats of the inlet, especially along the mainstem. Sediment samples were frozen at the cannery and remained frozen until processed in the laboratory in Baltimore. The samples were processed for physical characteristics by procedures outlined by Buchanan and Kain (1971):

- Chemical oxidation to determine the carbon content of sediments available to the benthos
- Combustion at 500°C to determine total carbon content
- Wet sieving through a 63-µm screen to determine the percentage of silts and clays
- Dry sieving through a series of screens to determine the median diameter and distribution of sediment particles.

Since salinity and temperature of the water are environmental factors that also determine the kinds and relative abundance of benthic organisms in an area, point measurements of these parameters were taken at several depths at each station when the biological samples were collected. Salinity and temperature measurements were also made throughout Hawk Inlet during sampling.

B. PROCESSING METHODS FOR METALS ANALYSIS OF BIOLOGICAL TISSUE

To prepare freeze-dried samples for tissue metals analyses, living specimens were collected at the cannery and suspended for 24 hours in inlet water to purge intestinal tracts of sediments and other material. Shellfish were removed from shells using stainless steel and Teflon-coated instruments. All instruments were soaked in 4N reagent-grade nitric acid overnight and triple rinsed with double-distilled water before use.

Samples were homogenized using an acid-washed glass or polyethylene blender container with a stainless steel and Teflon blade assembly. Triple-distilled water was added to each sample to provide sufficient fluidity for blending. Blended samples were then poured back into the original bottle, along with rinse water from the blender container.

Homogenized samples were frozen, bottle caps were loosened, and the samples were freeze dried for at least 96 hours at a temperature of -5°C or lower. Samples were weighed daily, and freeze drying was continued until no additional weight loss was observed. Sample bottle caps were then tightened, and the samples were shipped to analytical laboratories for metal and hydrocarbon determinations.

C. PROCESSING METHODS FOR METALS AND HYDROCARBON ANALYSES OF SEDIMENTS

Sediment samples to be used for metals and hydrocarbon determinations were frozen at the cannery in Teflon containers and dried to a constant weight in the laboratory. Sediments were treated by acid digestion and then analyzed as described below. Hydrocarbons were extracted using a dichloromethane-methanol mixture. Saturated (F_1) and unsaturated (F_2) fractions were separated by column chromatography and concentrated on a rotary evaporator. Total lipids were measured gravimetrically. Composition of fractions was determined by gas chromatography.

D. METALS CONCENTRATIONS ANALYTICAL METHODS

Metals analyzed for included zinc, copper, lead, manganese, nickel, chromium, silver, cadmium, mercury, arsenic, and selenium. Two blind standard biological tissue samples from the National Bureau of Standards were included in the set of samples sent out for analysis to provide a measure of the accuracy of the analyses. The two standard materials were albacore tuna (NBS Research Materia 50) and bovine liver (NBS Standard Reference Material 1577). Only a number was used to mark the polyethylene bottles containing the freeze-dried samples. Thus, the analytical laboratory technicians did not know the type of tissue being analyzed or which samples were replicates. This procedure complicated the analysis of samples but ensured unbiased results.

Sample analysis was performed by Energy Resources Co., Inc. (ERCO), Cambridge, Massachusetts. Each freeze-dried sample container was opened on a laminar-flow clean bench and three

representative subsamples were removed from each specimen. Acid-rinsed plastic or Teflon utensils were used for all sample manipulations to avoid contamination. One subsample was used for the determination of Ag, Cd, Cr, Cu, Mn, Ni, Pb, and Zn. The second subsample was used for determination of Hg. The third subsample was used for determination of As and Se. Analyses of Ag, Cd, Cr, Cu, Hg, Mn, Ni, Pb, and Zn were conducted according to methods described by Goldberg (1976) and U.S. EPA (1977, 1979). Analyses for As and Se were conducted according to methods described by Agemian and Cheam (1978).

III. RESULTS

A. SEDIMENT AND PHYSICAL/CHEMICAL DATA

The physical and chemical characteristics of the water (e.g., salinity, temperature) and mechanical properties of sediments (e.g., carbon content, silt-clay content, median diameter) generally are the major environmental factors determining the kinds and abundances of benthic organisms that occur in soft-bottom habitats. Data on these factors were collected at each study site jointly with biological samples and are summarized in Table 2.

Salinities in Hawk Inlet were polyhaline to marine (22 to 32 ppt) and varied 2 to 5 ppt over a tidal cycle. Salinity also varied with depth. Highest salinities (32 ppt) occurred in deepest areas. Water temperature decreased with depth: the highest water temperature (about 13°C) occurred in surface waters at the head of the inlet, while lowest temperatures (8.5°C) occurred in deep water in the center of the inlet. Variations in salinity and temperature with depth resulted in a stratified water column. These data were similar to those collected from Hawk Inlet during summers of other years, suggesting that the 1981 data were representative of "normal" conditions (e.g., Binkerd and Johnston, 1980; IEC, 1980; Noranda Exploration, Inc., 1978).

Salinities at the proposed dock site in Young Bay were much lower than those in Hawk Inlet -- 19 to 24 ppt compared to 25 to 32 ppt (Table 2). Water temperatures in Young Bay were comparable to those observed in shallow water habitats of Hawk Inlet (Table 2). No previous salinity or temperature data were available from Young Bay for comparison.

Sediments composing intertidal regions of the Greens Creek delta were heterogeneous, and consisted of isolated patches of gravel, cobble, and large rocks on top of sands. The physical properties of the sand appeared to be similar over most of the

Table 2. Summary of physical/chemical and sediment data collected at benthic sampling locations between 8 and 14 July 1981. Dashes indicate determinations were not made.

Station Location and Designations	Bottom Depth (m)	Water* Column Salinity (ppt)	Temp. (°C)	SEDIMENT CHARACTERISTICS: With Carbonates: Inter-stitial Salinity (ppt)	Moisture (%)	Carbonate (%)	Organic (ignition) (%)	Organic (wet oxidation) (%)	Silts & Clays (%)	Median Diameter (ϕ)	Skewness	Quartile Devia-tion	Without Carbonate: Silts & Clays (%)	Median Diameter (ϕ)	Skewness	Quartile Devia-tion
Hawk Inlet Samples																
1) Green's Creek Delta	Mid-littoral	29.8	11.8	25.0	22.6	5.1	2.29	0.31	7.8	0.21	-0.04	1.28	7.2	0.57	-0.20	1.42
2) Green's Creek Delta	8	26.8	11.1	17.0	26.7	4.0	2.52	0.16	1.9	0.53	-0.18	1.60	1.9	0	-0.05	1.60
3) Cannery	Mid-littoral	29.8	11.2	25.0	54.1	3.4	2.41	0.34	3.2	1.10	-0.42	1.59	5.3	1.08	-0.38	1.65
4) Cannery	63	32.0	8.9	32.5	64.4	0.0	15.45	4.79	48.8	3.95	1.00	1.95	—	—	—	—
5) Head of Inlet	Mid-littoral	27.2	13.4	26.0	30.3	0.6	3.31	0.98	32.1	1.40	-1.13	3.58	—	—	—	—
6) Head of Inlet	5	27.2	13.4	28.0	36.3	1.8	3.66	1.00	17.7	-2.05	-2.40	3.75	—	—	—	—
Young Bay Samples																
7) North Reference Young Bay	Mid-littoral	—	—	—	2.0	12.8	1.06	0.02	0.3	-2.20	-0.15	1.75	0.3	-2.45	0.03	1.83
8) North Reference Young Bay	3	—	—	24.0	36.5	9.8	2.40	0.25	2.0	1.93	0	0.40	2.2	1.98	0.25	0.63
9) Dock Site Young Bay	Mid-littoral	19.3	12.4	23.5	12.8	28.5	1.40	0.07	1.6	-2.40	-0.03	1.13	1.1	-3.10	0.40	1.05
10) Dock Site Young Bay	3	19.3	12.4	22.5	25.1	12.4	2.58	0.16	2.2	1.78	0.05	0.50	3.0	1.68	0.18	0.50
11) South Reference Young Bay	Mid-littoral	—	—	22.0	8.8	25.6	1.29	0.11	0.3	-2.25	0.73	2.98	0.8	-4.25	-6.94	2.04
12) South Reference Young Bay	3	—	—	23.5	25.5	17.0	2.26	0.29	1.4	1.39	0.09	0.79	1.9	1.39	0.11	0.78
Hawk Inlet Misc. Samples																
13) Entrance to "Mud Hole" area	12	28.5	13.0	28.0	62.0	1.7	5.74	1.80	38.0	3.35	-0.04	1.43	—	—	—	—
14) Inside "Mud Hole" area	12	29.0	12.9	30.0	28.4	4.4	6.99	0.56	9.6	-3.30	7.23	3.93	—	—	—	—
15) Upstream of cannery	40	31.9	9.9	30.0	51.5	1.8	9.80	2.49	47.1	3.87	1.16	2.23	—	—	—	—
16) Cannery	25	26.9	10.9	29.5	30.0	1.2	4.26	1.05	13.5	1.95	-2.13	2.93	—	—	—	—
17) Near proposed tailing pond discharge	60	27.3	10.6	29.0	63.6	0.4	5.82	1.81	18.7	3.33	-0.07	0.52	—	—	—	—

*Salinity was measured in bottom water of subtidal sample sites and in water over intertidal sample sites just before or after samples were collected.

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delta. However, the amount of gravel and cobble varied considerably from location to location. Intertidal sediments from the site where biological samples were collected were classified as poorly sorted, coarse sands, as indicated by large median diameters and skewness and quartile deviation values (Table 2). They contained about 7 to 8% silts and clays, 2.3% organic material, and 5% carbonates (Table 2). The silt-clay and organic content were higher than anticipated. The large populations of mussels (e.g., Mytilus edulis), seaweeds (e.g., Fucus disticus), and other unidentified invertebrates at the collection site probably contributed to the deposition of fine-grained materials, either through biodepositional processes (such as feeding activities and feces production) or by slowing down currents and entrapping finer sediment particles. Relatively large quantities of fecal material from invertebrates were noted on the surface of sediments.

Subtidal sediments from the Greens Creek delta were also heterogeneous and were similar to intertidal sediments (Table 2). However, the silt-clay content was slightly lower. The poor sorting and heterogeneous nature of sediments composing subtidal and intertidal habitats of the Greens Creek delta indicated that sediments of the delta were glacial deposits that had been mixed with modern deposits and reworked by tidal action.

Intertidal sediments in the vicinity of the cannery were poorly sorted, coarse sands containing about 3% silts and clays, 2.4% organic material, and 3.4% carbonates (Table 2). Mechanical properties (e.g., median diameter and silt-clay content) of cannery deposits were similar to those from the Greens Creek delta, suggesting that intertidal sediments from the cannery site could also have been derived from glacial and recent erosion processes associated with Cannery Creek. Based on observations, intertidal sediments at the cannery were not as heterogeneous as at the Greens Creek delta.

Subtidal sediment characteristics in the vicinity of the cannery varied with depth. At 25 m, sediments were coarse-grained muddy-sands composed of about 14% silts and clays, 4% organic material, and 12% carbonates. At 63 m, sediments contained about 50% silts and clays, 15% organic material, and essentially no carbonates. Deep-water sediments north and south of the cannery were generally similar in physical properties to those at the cannery site except they contained less organics (5.74 to 9.8%) and more sands. The higher organic content of sediments in the immediate vicinity of the cannery could have been a result of discharg associated with cannery operations. However, since this part of the fjord was also the deepest, some undetermined portions of the organic content of sediments there could also have been the result of natural sedimentation processes. The muddy, deep-water sedimen from the central area of Hawk Inlet, especially in the vicinity of the cannery, contained considerable amounts of plant detritus. Although the extent of the muddy sediments in deep-water environments of Hawk Inlet was not quantitatively determined, they appeared to extend from near the cannery to the head of the inlet along the eastern shore. Deep-water hard bottoms appeared to be confined to the region near the Greens Creek delta and the western shore.

Intertidal sediments at the head of the inlet were coarse muddy-sands that contained about 32% silts and clays, 3.3% organic material and 0.6% carbonates (Table 2). Properties of subtidal sediments at the head of the inlet were similar to those of intertidal sediments except they contained less silts and clays (≈17%). Large beds of bull kelp, <u>Nereocysts luetkeana</u>, occurred in this area. Detritus, especially kelp-like material, appeared to constitute much of the organic material in sediments. The sand componen of sediments at this site was poorly sorted and could have been of glacial origin. Large boulders, rocks, and cobble were frequently observed scattered throughout the intertidal zone, another indication that some of the deposits at this site were probably derived from glacial processes. The high silt-clay content of sediments at the head of the inlet suggested the area was a depositional environment for fine sediment particles.

Intertidal sediments at the proposed dock site in Young Bay were predominantly cobble mixed with sand. These poorly sorted sediments contained 1.6% silts and clays, 1.4% organic material, and 28% carbonates. Properties of intertidal sediments at the northern and southern reference areas were similar to those at the dock site.

Depth in Young Bay increased rapidly with distance from shore beginning at about 100 to 200 m offshore where depth was 3 to 4 m. The cobble intertidal sediments rapidly changed to sand along this gradient. No sediment samples were obtained from depths greater than 3 m. Subtidal sediments at the proposed dock site were well-sorted, medium sands containing 2.2% silts and clays, 2.6% organic material, and 12.4% carbonates. Properties of subtidal sediments at the northern and southern reference areas were similar to those at the dock site. The sediment characteristics in the Young Bay samples suggested that the sample sites were located in moderate-energy environments (i.e., that the area was exposed to some wave activity). The large amounts of carbonates in sediments at this location were predominately shell fragments of molluscs and barnacles.

Sediment characteristics generally appeared to be similar from replicate to replicate at all sample sites where biological samples were collected (i.e., bottoms were homogeneous), except for the subtidal stations located at the head of Hawk Inlet and in the vicinity of the Greens Creek delta. At these two locations, there was considerable replicate-to-replicate variability in sediment characteristics and volume of material collected by the grab sampler. At both locations, rocks, cobble, and large shell fragments appeared to be dispersed among the finer grained sediments, and properties of sediments changed rapidly over distances of tens of meters. Because only a single sediment sample was collected with the five biological samples from each of these sites, the effects of the heterogeneous nature of the sediments on the biota could not be quantitatively determined -- only a qualitative association could be established.

The data collected on sediment metals levels in Hawk Inlet are summarized in Table 3. The concentrations observed were comparable to levels reported for "pristine" and "unpolluted" marine areas of the northeast Pacific coast and were orders of magnitude lower than levels reported for "polluted" or "semi-polluted" environments such as Baltimore or Los Angeles Harbors (e.g., Pfeiffer et al., 1972). Station-to-station variability in metals levels did not appear to be closely related to station-to-station variability in physical properties of sediments. These data were quantitatively similar to data previously collected from Hawk Inlet by VTN, indicating that year-to-year variability in sediment metals is small (IEC, 1980).

Sediment burdens of oil and grease, lipids, aliphatic hydrocarbons, and aromatic hydrocarbons at Hawk Inlet stations are also summarized in Table 3. Sediment levels of oil and grease were 2 to 6 times the levels observed in "unpolluted" environments (Pfeiffer et al., 1972). Levels of lipids, aliphatics, and aromatics were also higher by about a factor of 2 than would be expected for "unpolluted" nearshore marine environments (Malins, 1977). Results of gas chromatography are presented in a recent report by Energy Resources Company, Inc. (1981). Chronic petroleum contamination, as evidenced by high-molecular weight unresolved compounds, was the predominant source of hydrocarbons in the intertidal and subtidal samples taken at the cannery. A spill of diesel fuel of undetermined size (<1000 gallons) in early July could have accounted for these results. Terrigenous (land) plant hydrocarbons represented by n-alkanes with odd-numbered carbon chains, were present in all samples and were most abundant in those from the Greens Creek delta area. Marine biogenic (algal) hydrocarbons were predominant in samples from the head of the inlet. These data indicated that the only stations contaminated by anthropogenic hydrocarbons were those at the cannery site.

Table 3. Summary of data in sediment burdens of heavy metals and hydrocarbons in Hawk Inlet for samples between 8 and 14 July 1981.

Sample		Moisture (%)	METALS CONCENTRATION (ppm dry wt.)												Oil & Grease (µg/g dry wt.)	Total Lipids (mg/g dry wt.)	Aliphatics (F_1) (mg/g dry wt.)	Aromatics (F_2) (mg/g dry wt.)
			Ag	As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Se	Zn				
GREENS CREEK DELTA	Intertidal	78.39	<0.22	20	0.24	43	18	0.078	320	26	11	0.028	59	630	0.258	0.029	0.023
	Subtidal	81.14	<0.2	22	<0.15	57	17	0.35	370	43	8.4	0.55	110	270	0.118	0.003	0.004
CANNERY	Intertidal	33.16	0.39	24	1.0	60	39	0.15	250	39	19	1.7	110	2300	1.01	0.052	0.95
	Subtidal	76.33	<0.14	13	0.22	14	18	0.049	240	17	4.8	0.30	50	930	0.223	0.007	0.013
HEAD OF INLET	Intertidal	40.37	<0.22	18	1.3	35	27	0.11	250	23	8.7	0.79	57	820	0.919	0.30	0.099
	Subtidal	74.51	<0.15	17	0.48	55	16	0.034	320	42	7.4	0.38	110	1100	0.128	0.002	0.004

B. METALS CONCENTRATIONS IN BENTHIC INVERTEBRATES

Three types of benthic organisms were collected at the cannery for analysis of metals burdens in tissues: the soft clam (*Mya arenaria*), the mussel (*Mytilus edulis*), and starfish (species probably *Pisaster ocharceus*). Results of analyses of metal levels in tissues, summarized in Table 4, were comparable to or lower than those reported for mussels and clams collected at the Greens Creek delta in 1980-1981 (Richkus and Johnson, 1981). Differences in concentrations of metals between *Mya* and *Mytilus* are evident in Table 4. Arsenic, cadmium, and lead tended to be higher in *Mytilus* while copper and manganese were higher in *Mya*. Values for zinc and copper in both *Mya* and *Mytilus* were comparable to values reported for these species in marine waters of British Columbia (Table 5). Values for most metals were lower in starfish than in shellfish. No literature data were available for comparison to the starfish data. However, the starfish is a predator on clams, mussels, and other benthic organisms, and thus should be an indicator of prevailing bioaccumulation of metals and other toxic substances through the marine food web at this location. In general, these data indicated the absence of metal pollution near the cannery and could serve as baseline data for future monitoring of the cannery area.

C. QUANTITATIVE MACROBENTHIC DATA

The quantitative macrobenthic data collected during July 1981 are presented in Appendix B and summarized in Tables 6 and 7. Juvenile organisms dominated collections at all locations, indicating that the sampling program was conducted during or shortly afte the peak summer recruitment period. The peak recruitment period for most benthic communities of the northeast Pacific is summer (Lie, 1968). Thus, numerical values presented here are higher than would be the case if sampling had been conducted at other times of the year, when these juveniles had been exposed to predation and other sources of natural mortality for a period of time.

Table 4. Metals concentrations in tissue samples of the indicated organisms taken from the vicinity of the cannery in Hawk Inlet between 8 and 14 July 1981.

Sample No.	Tissue	Number of Individuals	Sample Wet Wt. (g)	Metals Concentration (μg/g dry wt.)										
				Ag	As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Se	Zn
1	Clam (*Mya*)	2	55	21	1.9	0.69	1.6	14	0.041	15	1.7	<0.34	3.2	100
2	Clam (*Mya*)	2	49	9.7	1.9	0.40	1.1	10	0.044	7.4	0.96	<0.28	2.9	48
3	Clam (*Mya*)	2	44	7.3	3.4	0.78	1.4	18	0.067	17	2.2	<0.41	4.1	140
4	Clam (*Mya*)	2	41	2.4	2.7	1.4	1.1	16	0.066	15	1.7	<0.33	4.3	130
5	Clam (*Mya*)	2	40	5.3	3.5	0.81	1.7	22	0.071	23	2.9	0.74	4.7	110
6	Mussel (*Mytilus*)	7	23	9.3	4.0	9.0	1.8	7.3	0.066	14	2.1	0.75	2.7	120
7	Mussel (*Mytilus*)	7	38	11	4.0	5.8	1.4	8.1	0.10	12	0.65	1.1	1.8	94
8	Mussel (*Mytilus*)	7	40	8.1	3.7	5.2	2.1	6.8	0.063	11	1.1	0.61	2.1	100
9	Mussel (*Mytilus*)	7	45	5.7	2.9	3.7	0.84	5.7	0.049	6.4	0.50	0.33	2.6	76
10	Mussel (*Mytilus*)	7	35	5.5	4.1	14	1.4	6.9	0.073	9.8	0.87	1.5	2.8	110
21	Starfish	1	31	0.19	1.8	2.6	1.2	6.8	0.042	13	1.1	3.3	2.9	70
22	Starfish	1	34	0.24	2.6	3.3	1.0	5.4	0.058	8.8	0.68	0.99	3.4	87
23	Starfish	1	24	0.10	2.6	2.2	1.3	8.0	0.019	11	0.69	3.0	3.0	96
24	Starfish	1	31	1.1	2.7	2.7	0.93	8.0	0.056	8.2	0.46	1.5	3.5	100
25	Starfish	1	18	0.12	2.1	1.9	1.7	4.6	0.037	7.5	0.74	0.95	3.4	74
26	Bovine Liver (NBS)	—	—	0.045	<7.9	0.31	0.56	210	0.005	11	0.28	0.42	1.1	140
27	Albacore Tuna (NBS)	—	—	<0.01	<5.7	0.049	0.51	3.6	0.65	<2.0	0.39	0.49	3.1	15
16	Coho Smolt	9	22	0.53	<10	0.14	0.77	3.8	1.14	18	<0.35	<0.35	1.6	170
17	Coho Smolt	9	23	0.86	<11	0.13	<0.2	3.7	0.13	16	<0.41	<0.41	1.4	190
18	Coho Smolt	9	23	0.44	<5.3	0.10	0.23	2.5	0.095	14	0.21	<0.19	1.3	140
19	Coho Smolt	9	23	0.39	<11	0.13	<0.2	3.3	0.12	15	0.4	<0.4	1.6	150
20	Coho Smolt	9	26	0.28	<10	0.13	0.65	3.6	0.11	23	0.69	<0.36	1.6	150

Table 5. Metals concentrations, µg/g (ppm dry weight), in invertebrates (all bivalve molluscs) of Rupert and Holberg inlets, British Columbia, 1971-1974. (From Waldichuk and Buchanan, 1980).

Station	Species	Sampling Date	Zn		Cu	
			Average	Range	Average	Range
Red Island (Rupert Inlet)	Macoma iris	Aug. 1971	260		460	
	"	June 1972	140		100	
	"	June 1973	340	300-380	330	310-350
SCUBA Stn. 6 (West of mill site)	"	June-Aug. 1971	233	110-370	57	42-71
	"	Sept 1971	170		70	
	"	June 1973	270	230-300	74	38-130
Apple Bay (Holberg Inlet)	"	June 1973	180		9	
	"	June 1974	156	140-180	34	9-61
Red Island	Mya arenaria	Aug. 1971	105		77	
"	"	June 1972	68		34	
"	"	June 1973	130	16-19	31	29-33
"	"	May 1974	81	61-110	28	24-33
SCUBA Stn. 6	"	Aug. 1971	135	110-160	19	13-24
"	"	Sept 1971	120	80-160	31	(31)[a]
"	"	June 1973	167	150-180	31	27-37
"	"	May 1974	63	42-110	22	12-31
Apple Bay	"	June 1972	140	(140)[a]	16	16-17
"	"	June 1973	133	110-160	28	13-55
"	"	May 1974	62	48-69	22	16-29
Red Island	Mytilus edulis	July-Aug. 1971	215	89-340	30	16-44
"	"	June 1973	220		87	
"	"	June 1974	98	33-120	15	13-20
SCUBA Stn. 6	"	July-Aug. 1971	145	100-190	35	17-52
"	"	June 1973	190		43	
"	"	May 1974	93	75-130	14	10-17
Apple Bay	"	June 1972	51		5	
"	"	June 1973	120		9	
"	"	May 1974	71	51-95	9	5-13

[a] All samples gave the same value.

Table 6. Number of benthic species collected at each sample site during July 1981 surveys.

Sample Sites	Intertidal	Subtidal
Hawk Inlet		
Greens Creek delta	36	80
Cannery	57	52
Head of inlet	36	41
Young Bay		
Northern reference area	15	33
Proposed dock site	21	27
Southern reference area	24	25

Table 7. Mean number of individuals per m^2 for macrobenthic organisms by major taxonomic groups.

	HAWK INLET					
	Greens Creek Delta		Cannery		Head of Inlet	
	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal
Polychaetes	4,206	19,775	11,038	5,222	24,313	3,494
Snails	675	2,047	1,643	108	4,779	519
Bivalves	156	1,300	2,588	1,581	15,896	3,665
Amphipods	338	3,682	9,485	153	156	39
Other crustacea	442	1,207	4,365	1,749	4,181	65
Other worms	676	977	2,340	594	182	161
Misc. species	78	847	274	0	52	0
Total All Species	6,391	29,835	31,733	9,407	49,558	7,943

	YOUNG BAY					
	Northern Reference Area		Proposed Dock Site		Southern Reference Area	
	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal
Polychaetes	1,675	7,826	1,075	17,533	1,600	906
Snails	350	0	546	86	2,200	96
Bivalves	300	583	13,075	346	6,050	3,375
Amphipods	0	3,083	200	6,450	0	195
Other crustacea	300	96	6,050	43	22,300	1,201
Other worms	1,075	162	3,400	87	2,300	4,611
Misc. species	75	0	375	0	150	0
Total All Species	3,775	11,750	20,246	24,545	3,460	10,384

The total number of species observed in samples and estimates of mean density of abundant species at all locations generally leveled off after four or five replicates, i.e., it is unlikely that significant numbers of new species would have been collected or estimates of mean density would have changed had additional samples or larger samples been collected. Five replicates of the sample sizes collected were thus considered sufficient to: (1) characterize the species composition and relative abundance of the organisms sampled and (2) establish a quantitative baseline for use in monitoring potential effects during mining operations.

Thirty-six species of macrobenthic invertebrates were collected from the sandy intertidal station on the Greens Creek delta (Table 6). Snails (e.g., Littorina sitkana), polychaetes (e.g., unidentified juvenile Capitellidae, Fabricia sabella, Spio filicornis, and Sternaspis scutata), shellfish (e.g., Mytilus edulis), and the isopod Gnorimosphaeroma oregonensis were numerically dominant organisms. The number of species observed in these samples was higher than that reported for the Greens Creek delta area by VTN (IEC, 1980), primarily because of the higher number of polychaete species in the present samples. Polychaete species were probably more numerous because the soft-bottom habitats which they inhabit were rigorously sampled in this study, while the VTN samples were random collections from the area. Macrobenthic densities in intertidal samples from the Greens Creek delta were within ranges reported for similar habitats along the northeast Pacific coast (Table 7), and the communities were typical of those expected for sandy, soft-bottom, mid-littoral habitats of the region (e.g., O'Clair et al., 1978; Broad et al., 1979).

More macrobenthic species were collected in subtidal samples from the Greens Creek delta than from any other sampling station (Table 6). One reason may have been the slightly higher salinities there, but more likely, more than one habitat was sampled, as indicated by the heterogeneity of the sediments at that location. Numerically dominant organisms were clams (e.g., Psephidia lordi), polychaetes (e.g., Armandia brevis, unidentified juvenile Chaetopteridae, Owenia fusiformis, Prionospio sp., and Spiophanes sp.), an unidentified amphipod species, and unidentified juvenile sea urchins (<2 mm). The species composition of the benthic community inhabiting this site was similar to that reported by IEC for subtidal areas near the cannery (IEC, 1980). Densities of abundant species and taxa (Appendix B and Table 7) were also similar to those reported for similar habitats along northeast Pacific coasts (IEC, 1980, O'Clair et al., 1978; Carey, 1979). Replicate-to-replicate variation in density of abundant species was larger at this site than at most other locations probably because the physical properties of the sediments varied greatly from replicate to replicate. Because of this large variability, any plans for monitoring studies in this region, or a similar habitat type, should include sampling at more than one station. In addition, a sediment sample should be taken with each biological sample collected. Only in this way can the biological variability associated with replicate-to-replicate variability in sediment properties be rigorously separated from that due to mining operations. These data indicated macrobenthic communities inhabiting subtidal habitats of the Greens Creek area were typical of shallow-water subtidal areas of the northeastern Pacific (e.g., Ricketts et al., 1939; Lie, 1968; O'Clair et al., 1978; Carey, 1979).

Intertidal samples collected from the vicinity of the cannery were dominated by bivalves (e.g., Macoma balthica and Mytilus edulis), snails (e.g., Littorina sitkana), and polychaetes (e.g., Fabricia sabella). A total of 57 species was collected from this habitat (Table 6), a slightly greater number than was collected from other intertidal habitats in Hawk Inlet or Young Bay. However, sample sizes at the cannery were about twice those at other sample sites, and the number of species in benthic collections is known to increase as the area sampled increases. The number of benthic species per unit area sampled at the cannery was lower or about equal to that at other Hawk Inlet sample sites. Over 50 macrobenthic species were observed in the vicinity of the cannery

by VTN, and the VTN species list includes most of the numerically dominant species observed in this study (IEC, 1980). Macrobenthic densities observed in the intertidal habitat sampled at the cannery were within ranges that would be expected from similar habitats (Table 7), and the species composition indicated a macrobenthic community typical of the northeast Pacific coast (e.g., O'Clair et al., 1978; Broad et al., 1979).

Subtidal samples from the vicinity of the cannery contained about the same number of species as intertidal samples from this location (Table 6). Polychaetes (e.g., unidentified juvenile Capitellidae, Cossura sp., Harmothoe imbricata, Lumbrineris sp. Pholoe minuta, and Prionospio sp.) were the dominant organisms. The species composition of the macrobenthic community at this site was similar to that reported for a similar habitat by VTN (IEC, 1980). Standing stocks in subtidal habitats in the vicinity of the cannery were in ranges reported for mud habitats of the northeast Pacific coast (Table 7; Lie, 1968; O'Clair et al., 1978; Carey, 1979). There were no previous data on densities in this habitat for comparison. Characteristics of deep-water mud communities in Hawk Inlet were similar to those of deep-water mud communities of the northeast Pacific coast where large amounts of organic material accumulate (Lie, 1968).

Thirty-six species of macrobenthic invertebrates were collected in samples from the muddy-sand intertidal flat at the head of the inlet (Table 6). Snails (e.g., Lacuna variegata and Moelleria sp.), clams (e.g., Mysella sp.), polychaetes (e.g., unidentified juvenile Capitellidae, Haploscoloplos elongatus, Nephtys ciliata, and unidentified polychaetes of the family Spionidae), and an unidentified mysid shrimp were the dominant organisms collected. These habitats were highly productive benthic habitats and harbored the highest standing stocks observed (Table 7). Communities inhabiting this site appeared to be typical of those in mud flats of the northeast Pacific coast (e.g., Ricketts et al., 1939; O'Clair et al., 1978).

Subtidal samples from the head of Hawk Inlet contained fewer individuals, by an order of magnitude, and about the same number of species as did intertidal samples from this area (Tables 6 and 7). Clams (e.g., *Mysella* sp.) and polychaeate worms (e.g., *Haploscoloplos elongatus*) were the dominant organisms both here and in intertidal samples at this location. Replicate-to-replicate variability in species composition and abundances in subtidal habitats at this location were relatively large, probably because of the observed replicate-to-replicate variation in sediment characteristics. Plans for future field studies at the head of the inlet should include more than one station from subtidal habitats. In addition, a sediment sample should be collected with each biologica sample to rigorously account for biological variability associated with replicate-to-replicate variability in sediment properties and to better describe sediment characteristics of the region. The data reported here indicated that subtidal habitats at the head of Hawk Inlet were very productive and were inhabited by macrobenthic communities typical of the northeast Pacific coast (e.g., Ricketts et al., 1939; O'Clair et al., 1978; Lie, 1968). One reason for the relatively low densities in this habitat could have been predation by bottom-feeding flatfish, which are known predators of soft-bottom benthic organisms. Large numbers of these fish were observe in subtidal areas at the head of the inlet during sampling.

The cobble intertidal habitats of Young Bay were characterize by few species as is typical of moderate-energy cobble beach enviro ments (Table 6). The blue mussel (e.g., *Mytilus edulis*) was a dominant species at all three intertidal sampling sites. Most of the *M. edulis* collected were juveniles (<1 mm in shell length) attached to the cobble. Other dominant species were limpets (e.g., *Acomacia digitalis*), snails (e.g., *Littorina sitkana*), polychaetes (e.g., unidentified juvenile Capitellidae, *Fabricia sabella*), isopods (*Gnorimosphaeroma oregonensis*), clams (e.g., *Protothaca staminea* and *Psephidia lordi*) and other segmented worms (e.g., *Dinophilidae* sp.). Data on the species composition of comparable habitats were not available for the Young Bay area, but the composition of the epifaunal community on the intertidal rocks and ledges in the Young Bay area was similar to that for rocky intertidal habitats in Hawk Inlet and typical of that expected for cobble beaches along the northeast Pacific coast (IEC, 1980; O'Clair et al., 1978; Ricketts et al., 1939). Shells of the butter clam, *Saxidomus giganteus*, and the goeduck, *Panope generosa*, occurred along the beach, and siphons of these clams were observed by divers collecting subtidal samples. However, these clams burrowed too deep to be collected in the core samples for this study. Densities for the cobble intertidal habitats in Young Bay are summarized in Appendix B and Table 7. The distributions of dominant species characteristic of this habitat, particularly *Mytilus edulis*, were patchy, as indicated by the large replicate-to-replicate variability in their densities. This variability was typical of moderate-energy cobble beaches, where physical disturbances play a major role in determining community characteristics and abundance of dominant organisms (O'Clair et al., 1978). These data indicated that the cobble beaches in Young Bay were inhabited by a community typical of the northeast Pacific coast (Ricketts et al., 1939; O'Clair et al., 1978).

Sandy subtidal samples from Young Bay contained about twice as many species as intertidal samples (Table 6). Dominant species in this habitat were clams (e.g., *Macoma balthica*, and *Protothaca staminea*), polychaetes (e.g., *Aricidea* sp., *Armandia brevis*, *Chaetozone setosa*, *Glycinde* sp., *Nephtys* sp., and *Spiophanes* sp.), and an unidentified amphipod of the family Lysianassidae. The species composition of these samples appeared to be typical of that anticipated for moderate-energy shallow water coastal embayments (e.g., Lie, 1968; Carey, 1979; O'Clair et al., 1978). Densities for the sandy subtidal habitats of Young Bay were generally within ranges reported for similar habitats along the northeast Pacific coast (Lie, 1968; Carey, 1979; O'Clair et al., 1978). The fauna at the southern reference area comprised slightly fewer species, lower abundances of polychaetes, and higher abundances of the clam, Macoma balthica, than those at the dock site and the northern reference area (which were very similar to each other). These These differences could have been due to the slight variations in sediment characteristics noted between this station and other subtidal sample sites in Young Bay. The more protected location of the southern reference area, compared to the other two subtidal Young Bay stations, may have also contributed to the results.

IV. DISCUSSION, SUMMARY, AND CONCLUSIONS

A. DISCUSSION

- Species composing soft-bottom benthic communities feed directly on phytoplankton (filter feeders) and seaweeds (grazers), or they utilize carbon from primary producers and other sources after it has been incorporated into sediments (deposit feeders). The kinds and relative abundances of benthic organisms (i.e., benthic community structure) observed at a location are generally considered a good indicator of environmental conditions characteristic of that location. Temporal changes in the kinds and abundances of soft-bottom benthic organisms are also good indicators of changes in environmental conditions, and surveys of organisms composing soft-bottom benthic communities are frequently major elements of baseline studies or monitoring programs associated with development activities.

- Species composing soft-bottom benthic communities are generally important food items (especially as juveniles) in the diets of higher trophic levels, such as bottom-feeding fish (e.g., flounders and other flat fish), crabs (e.g., dunginess), and small mammals (e.g., otters). They are thus important intermediate linkages in marine food webs through which energy and materials pass to higher trophic levels. Many of the higher trophic levels that feed upon soft-bottom benthic organisms are harvested by commercial and recreational fisheries.

B. SUMMARY

- Soft-bottom habitats are a dominant habitat type at the sites of proposed developments in Hawk Inlet and in nearshore regions of Young Bay. Biological and sediment samples were collected from the major soft-bottom habitats at these locations to provide quantitative baseline data. The data collected are useful:

  -- To gauge the importance of these habitats to the marine environment, particularly to higher trophic levels

  -- To determine the vulnerability of these habitats to proposed development, based on the kinds and relative abundances of organisms observed.

- Rocky habitats are also a predominant habitat type occurring in both Hawk Inlet and at the site of the proposed docking facility in Young Bay. The characteristics of rocky intertidal communities in Hawk Inlet were qualitatively sampled and characterized previously in reports prepared for Noranda (Noranda Exploration, Inc., 1978; IEC, 1980). Benthic communities inhabiting rocky intertidal areas of Young Bay appear to be composed of species typical of rocky coasts of the northeast Pacific and similar to those occurring in Hawk Inlet.

- Benthic habitats sampled in Hawk Inlet were:

  -- Sandy intertidal areas (Greens Creek delta and cannery)

  -- A muddy-sand tidal flat (head of Hawk Inlet)

  -- A deep-water mud area (in the vicinity of the cannery)

  -- A gravel/sand subtidal bottom (Greens Creek delta)

  -- A muddy-sand subtidal area (head of Hawk Inlet)

  The physical nature of the bottom at some of the sample sites was heterogeneous, probably because of their glacial origins. Cobble, gravel, and boulders were dispersed throughout the area and provided habitats for benthic organisms that were not quantitatively sampled by this survey. However, the sand and mud under the cobble and rocks were similar to that sampled and probably contained similar kinds and relative abundances of benthic organisms. Thus, information obtained by this survey is considered representative of major soft-bottom benthic habitats in Hawk Inlet.

- Habitats sampled in Young Bay were moderate-energy cobble beachs and coarse nearshore sand sediments. A sand-to-cobble gradient occurred from depths of about 3 to 4 m up to intertidal areas at all Young Bay sample locations. The habitats sampled by this survey compose the majority of available nearshore habitats in the Fowler Creek area of Young Bay. South of the southern reference area, cobble intertidal beaches slowly grade into coarse sand beachs. The coarse sand beach habitat was not sampled because it was sufficiently south of the location of the proposed docking facility to remain unaffected by construction or operations of the proposed docking facility.

- The number of replicate biological samples collected at all sites was generally sufficient to characterize the species composition and to determine relative abundances of macrobenthic organisms inhabiting soft-bottom sediments.

- Total densities (and presumably productivity) of benthic organisms were similar to or slightly higher than those anticipated from similar habitats along the northeast Pacific coast following peak recruitment.

- Standing stocks of most abundant species at all stations were dominated by juveniles, suggesting sampling coincided with the peak summer recruitment period. Juveniles are generally the fraction of soft-bottom benthic populations selectively eaten by predators.

- The species compositions of soft-bottom intertidal and subtidal benthic assemblages in Hawk Inlet and Young Bay were typical of what would be expected from similar habitats along the northeast Pacific coast. Species compositions were different between intertidal and subtidal habitats, between sand and mud habitats, and between soft-bottom and cobble habitats. Sample sites where physical characteristics were comparable were inhabited by benthic communities composed of similar species. The findings imply that soft-bottom benthic communities in the Hawk Inlet/Young Bay area are good indicators of existing environmental conditions as well as changes in these conditions, i.e., those likely to be associated with development of the area. The physical/chemical environmental factors can be measured and associated with species distributions. These communities are thus suitable as elements of a monitoring program.

- Sediment loads and macrobenthic body burdens of metals in the sampled areas were similar to those reported for "unpolluted" areas.

- Hydrocarbon burdens in sediments were high. However, gas chromatography demonstrated that the high values near the delta and at the head of the inlet were of natural origin, while those at the cannery were a result of chronic petroleum contamination.

C. CONCLUSIONS

- The data presented here demonstrate that benthic communities in all areas sampled are typical for the northeast Pacific. The quantitative data presented provide an excellent baseline for use in monitoring to ensure the detection of any effects of mine operation.

- Benthic communities in Young Bay are composed of species that would be insensitive to development of the proposed docking facility. Dominant species there are adapted to stressful moderate-energy environments since cobble and sands are constantly being moved by waves. The proposed docking facility will not alter the dynamic nature of the habitat, but its pilings will provide additional habitat for epifaunal species such as barnacles and mussels, which presently do not occur in offshore regions.

- Benthic communities occurring in Hawk Inlet are relatively insensitive to the potential environmental alterations associated with development of the mine. Most of the dominant species are ubiquitous organisms and can tolerate a wide range of stresses. Operation of the cannery in Hawk Inlet has apparently not had significant long-lasting, adverse effects on distributional patterns. Impacts associated with the proposed mining facility would be less in magnitude than those associated with the cannery.

V. REFERENCES

Agemian, H., and V. Cheam. 1978. Simultaneous extraction of mercury and arsenic from fish tissues, and an automated determination of arsenic by atomic absorption spectrophotometry. Analyt. Chim. Act. 101:193-197.

Binkerd, R.C. and H.G. Johnston. 1980. Hydrographic study of Hawk Inlet, using fluorescence tracer techniques. Prepared for Martin Marietta Corporation, Baltimore, Md.

Broad, A.C., A. Benedict, K.Dutton, H. Koch, D.T. Mason, D.E. Schneider, and S.V. Schonberg. 1979. Environmental assessment of selected habitats in the Beaufort and Chuchi littoral system. In: Environmental Assessment of the Alaskan Continental Shelf - Annual Reports of Principal Investigators for The Year Ending 1979. Volume III. Receptors - Fish, littoral, benthos, pp. 361-542. Prepared for the U.S. Department of Commerce (NOAA) and the U.S. Department of Interior (BLM).

Buchanan, J.B., and J.M. Kain. 1971. Measurement of the physical and chemical environment. In: Methods for the Study of Marine Benthos, pp. 30-50. N.A. Holme and A.D. McIntyre, eds. Oxford, England: Blackwell Scientific Publications.

Carey, A.G. 1979. The distribution, abundance, diversity, and productivity of the Western Beaufort Sea benthos. In: Environmental Assessment of the Alaskan Continental Shelf-Annual Reports of Principal Investigators for The Year Ending 1979. Volume III. Receptors - Fish, littoral, benthos, pp. 208-360. Prepared for the U.S. Department of Commerce (NOAA) and the U.S. Department of Interior (BLM).

Energy Resources Co., Inc. 1981. Results of petroleum hydrocarbon analyses of sediment samples provided by Martin Marietta Laboratories. Prepared for Martin Marietta Corporation, Baltimore, Md.

Goldberg, E.G. 1976. Strategies for marine pollution monitoring. New York: Wiley-Interscience, John Wiley and Sons. 310 pp.

IEC. 1980. Marine ecology baseline studies for the Greens Creek project, Admiralty Island, Alaska. Prepared for Noranda Exploration, Inc., by International Environmental Consultants, Denver, Colorado.

Lie, O. 1968. A quantitative study of benthic infauna in Puget Sound, Washington, USA, in 1963-1964. Fish Dir. Shr. Ser. Hav. Unders. 14:229-556.

Malins, D.C. 1977. Effects of petroleum on arctic and subarctic marine environments and organisms. In: Nature and Fate of Petroleum. Volume I. New York: Academic Press.

Noranda Exploration, Inc. 1978. Environmental data collection. Greens Creek project, Admiralty Island, southeast Alaska. Denver, Colorado.

O'Clair, C.E., J.L. Hanson, J.S. MacKinnon, J.A. Gharrett, N.I. Calvin, and T.R. Merrell. 1978. Baseline/reconnaissance characterization littoral biota, Gulf of Alaska and Bering Sea. In: Environmental Assessment of the Alaskan Continental Shelf-Annual Reports of Principal Investigators for The Year Ending 1979. Volume III. Receptors - Fish, littoral, benthos, pp. 256-415. Prepared for the U.S. Department of Commerce (NOAA) and the U.S. Department of Interior (BLM).

Pfeiffer, T.H., D.K. Donnelly, and D.A. Possehl. 1972. Water quality conditions in the Chesapeake Bay system. Prepared for the U.S. Environmental Protection Agency by the Annapolis Field Office of Region III. Annapolis, Md.

Richkus, W.A., and G.F. Johnson. 1981. Heavy metal concentrations in aquatic biota of Greens Creek, Zinc Creek and Hawk Inlet. Volume I. Text. Prepared for Noranda Mining, Inc., by the Martin Marietta Environmental Center, Baltimore, Md.

Ricketts, E.F., J. Calvin, and J.H. Hedgpeth. 1939. Between Pacific Tides. Stanford, California: Stanford Univ. Press.

U.S. Environmental Protection Agency. 1977. Methods for the sampling and analysis of priority pollutants in sediments and fish tissue. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.

U.S. Environmental Protection Agency. 1979. Manual of methods for the analysis of water and wastes. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio. EPA 600-4/79/020.

Waldichuk, M., and R.J. Buchanan. 1980. Significance of environmental changes due to mine waste disposal into Rupert Inlet. Fisheries and Oceans Canada, British Columbia Ministry of Environment.

APPENDIX A

HEAVY METALS CONCENTRATIONS IN JUVENILE COHO SALMON FROM A ZINC CREEK TRIBUTARY

HEAVY METALS CONCENTRATIONS IN JUVENILE COHO SALMON FROM A ZINC CREEK TRIBUTARY

The upper end of a small tributary of Zinc Creek is currently under consideration as part of the site of the tailings pond for the Greens Creek mining operation. The proposed pond would be created by building a dike, and the pond outflow would presumably be piped and discharged into Hawk Inlet. A possibility exists that metal levels in the tributary may rise as a result of the mining operation. To establish baseline levels of metals in juvenile coho salmon inhabiting the tributary, samples were collected during the July 1981 field trip and analyzed.

Field Methods

Juvenile coho salmon were collected on 12 July 1981 with four plastic minnow traps baited with salmon roe. Traps were set for 4 hours, approximately 100 yards apart, beginning where the tributary enters Zinc Creek. Fish were placed in polyethylene bags, put on ice, and later were frozen.

Processing and Analytical Procedures

Analytical procedures were the same as are described in the main text of this report. Fish guts were removed before whole fish were homogenized.

Results and Conclusions

Metal levels measured in freeze-dried fish tissue are presented in Table A-1. In comparison to data from Zinc Creek coho sampled in 1980 (Richkus and Johnson, 1981), silver values in 1981 were an order of magnitude lower, zinc and copper values were slightly higher, and mercury was slightly lower.

The significance of the large difference in silver values is not clear. The possibility of contamination and/or measurement error always exists. Values by other methods fall within the range of values found in other salmonid species, as is discussed in Richkus and Johnson (1981).

Table A-1. Metals concentrations in juvenile coho salmon taken from a Zinc Creek tributary.

Sample No.	Tissue	Number of Individuals	Sample Wet Wt. (g)	Metals Concentration (µg/g dry wt.)										
				Ag	As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Se	Zn
16	Coho juveniles	9	22	0.53	<10	0.14	0.77	3.8	1.14	18	<0.35	<0.35	1.6	170
17	Coho juveniles	9	23	0.86	<11	0.13	<0.2	3.7	0.13	16	<0.41	<0.41	1.4	190
18	Coho juveniles	9	23	0.44	<5.3	0.10	0.23	2.5	0.095	14	0.21	<0.19	1.3	140
19	Coho juveniles	9	23	0.39	<11	0.13	<0.2	3.3	0.12	15	0.4	<0.4	1.6	150
20	Coho juveniles	9	26	0.28	<10	0.13	0.65	3.6	0.11	23	0.69	<0.36	1.6	150

APPENDIX B

SUMMARIES OF QUANTITATIVE BENTHIC DATA

Table B-1. Number of macrobenthic organisms per m^2 by species in samples collected from the Greens Creek delta

GREENS CREEK DELTA

	Intertidal							Subtidal						
	1	2	3	4	5	$\bar{X}$	SD	1	2	3	4	5	$\bar{X}$	SD
Foraminifera														
Unidentified forams	64935	90909	64935	1.1E5	1.4E5	93351	30340				1794	763	512	789
Cnidaria														
Unidentified anemones								38					8	17
Platyhelminthes														
Acoela sp.									229				46	102
Unidentified flatworms		130	130			52	71							
Nematoda														
Unidentified nematodes					649	130	290	38					8	17
Rhynchocoela														
Unidentified nemertean (red)	130	260	260		1169	364	463	458	992	229	611	76	473	356
Unidentified nemertean (red w/white head)	260		130	260		130	130							
Phoronida														
Phoronopsis harmeri								305	305	229	878	534	450	265
Chaetognatha														
Unidentified chaetognath														
Gastropoda														
Acomacea sp (Limpets)	1169		260			286	506							
Alvinia sp.														
Boreotrophon pacificus														
Cylichna sp.								38		38	38		23	21
Lacuna variegata								3588	4542	153	76	76	1687	2197
Littorina sitkana	909	260	260	260		338	339							
Littorina scutulata	130				130	52	71	76	229	38			69	95
Moellaria sp.								687	305	114	38	153	260	258
Natica sp.														
Nucella emarginata														
Odostomia sp.														
Polinices pallidus														
Unidentified nudibranchs											38		8	17
Bivalvia														
Clinocardium ciliatum														
Lucinoma annulata														
Nuculana hamata														
Nucula tenuis														
Macoma balthica									153				30	68
Macoma calcarea														
Macoma nasuta														
Macoma obliqua														
Macoma sp.											38		8	17
Mya arenaria														
Mya arenaria siphon														
Mysella sp.			390	130		104	169	76	76	38			38	38
Mytilus edulis			130			26	58	38	76		38	76	46	32
Pandora filosa														
Panomya ampla								38		38	229		61	96
Protothaca staminia			130			26	58	76	191	76	38	305	137	110
Psephidia lordi								1107	3130	305	191	153	980	1265
Yoldia myalis														
Oligochaeta														
Oligochaetes														
Polychaeta														
Ampharetidae sp. 1											38		8	17
Ampharetidae sp. 2														
Arabellidae					130	26	58		38				8	17
Aricidea jefreysii										1107			221	495
Armandia brevis					130	26	58	4504	5191		1908	1985	2718	2114
Capitellidae(unidentified juvenile)			130			26	58							
Capitellidae (short)														
Chaetopteridae					260	52	116	1488	3053	153	1527	534	1351	1124
Chaetozone setosa									38		38		15	21
Chone sp.								496	229	114		458	260	215
Cossura longocirrata											114		23	51
Dorvillea sp.	130					26	58							
Eteone longa								153	153	229	114	267	183	63
Eunoe uniseriata														
Euchone analis								76		153	191	420	168	159
Exogone gemmifera			130		130	52	71	38	76	153			53	64
Fabricia sabella	909	130	1299	260	1948	909	752		76		76		30	42
Glycinde sp.					130	26	58				76	38	25	34
Gyptis sp.														
Harmothoe imbricata								229	496	305	191	153	275	136
Haploscoloplos elongatus (Orbiniidae)									76				15	34
Lumbrineris sp.														
Maldanidae sp. 1														
Nephtys ciliata								76		38	38	114	53	44
Nephtys sp. 1									114				23	51
Nephtys sp. 2														
Nephtys sp. 3														
Nereidae										38	38		15	21
Onuphis geophiliformis								114	38	38		153	69	63
Owenia fusiformis								114	1107	153	267	191	366	413
Pectinaria sp.								382	1794	267	114	534	618	675
Pholoe minuta	390		260	130	130	182	148		76	38		76	38	38
Phyllodoce groenlandica									38		38	38	23	21
Pilargidae														
Polydora socialis				130	390	104	169		38		38		15	21
Praxillella														
Prionospio malmgreni					520	104	232	12214	5153	3168	5191	2672	5680	3826
Prionospio (filament gills)														
Prionospio sp. (large eyes)								114					23	51
Potamilla sp.														
Scolelepis sp.														
Sphaerosyllis erinaceus									38	38			15	21
Sphaerosyllis sp.								916	1221	344	534	305	664	394
Spio filicornis	1299		1169		1169	727	666	38	114	38	153	114	91	51
Spiophanes sp.			130		779	182	339	370	15458	2252	8702	5878	6532	5939
Spionidae sp. 1 (forked nose)								76	76	38		114	61	43
Spionidae sp. 2 (stubby nose)								76			114	153	67	68
Spionidae sp. 3 (large eyes)									114				23	51
Spionidae sp. 4 (black cheeks)														
Sternaspis scutata	390	390	130	260	2857	805	1152				38		8	17
Syllis adamantea														
Syllis sp.	130	390	390			182	197							
Syllidae sp. 2				260	779	208	339							
Syllidae sp. 3								38						
Tharyx secundus														
Travisia sp. 1								38					8	17
Travisia sp. 2			260	260	909	286	382	38		114			30	50
Archiannelida														
Dinophilidae														
Protodriloides sp.														
Amphipoda														
Bateidae									76			114	38	54
Caprella laeviuscula									114				23	51
Corophium sp. 1				130	390	104	169	382	458	305		2214	672	879
Corophium sp. 2			260		260	104	142		76		2214	38	466	787
Gammaridae sp.														
Hyperiidae sp.											38		8	17
Lysianassidae sp. 1					260	52	116							
Lysianassidae sp. 2								38	38	344		344	153	175
Marinogammarus sp.									38				8	17
Mesogammaridae														
Oedicerotidae sp. 1											38	76	23	34
Oedicerotidae sp. 2								153					31	68
Photis sp.					130	26	58	153	267	344			153	155
Phoxocephalidae								153	305	38	38	114	130	110
Stenothoidae											38		8	17
Talitridae								305	305	191	687	382	374	188
Unidentified amphipod sp. 2					260	52	116	229	153	496	3511	3015	1481	1641
Unidentified amphipod sp. 3								38		114	38	38	46	42
Unidentified amphipod sp. 4								76		267		38	76	111
Cumacea														
Unidentified cumacean									191	114		38	69	83
Isopoda														
Asellota										38			8	17
Gnorimosphaeroma oregonense			520	260	130	182	217				38		8	17
Idotea aculatea									38			38	15	21
Tanaidacea														
Unidentified tanaids					130	26	58	267	38	229	114		130	116
Mysidacea														
Unidentified mysids														
Caridea														
Crangon munitella								38					8	17
Sclerocrangon alata														
Euphausiacea														
Unidentified euphausids											38		8	17
Copepods														
Cyclopiod copepod														
Unidentified Calanoid sp.								38			114	153	61	69
Unidentified Harpacticoid sp.	260		520	260	130	234	193	458	3740	38	76	305	923	1589
Ostracod														
Unidentified ostracods									38				8	17

GREENS CREEK DELTA

	Intertidal							Subtidal						
	1	2	3	4	5	$\overline{X}$	SD	1	2	3	4	5	$\overline{X}$	SD
Cirripedia														
Unidentified barnacles			1558			312	697	76	38	382		38	107	156
Paguroidea														
Pagurus sp.									38				8	17
Brachyura														
Unidentified crab								76	38			38	30	32
Unidentified zoea														
Arachnida														
Unidentified mite														
Unidentified Pseudoscorpionida														
Insecta														
Unidentified insect larvae			390			78	174							
Unidentified species								687	1145	1336	420	458	809	412
Echinodermata														
Unidentified sea urchins														
Unidentified sand dollars								38	114				30	50
Unidentified sea cucumbers														
Unidentified star fish														
Tunicata														
Unidentified tunicates														

Table B-2. Number of macrobenthic organisms per m^2 by species in samples collected in the vicinity of the cannery.

CANNERY

	Intertidal							Subtidal						
	1	2	3	4	5	X̄	SD	1	2	3	4	5	X̄	SD
Foraminifera														
Unidentified forams	3.0E5	2.0E5	1.1E5			1.2E5	1.2E5	2786	2176	2099	534	1374	1796	865
Cnidaria														
Unidentified anemones														
Platyhelminthes														
Acoela sp.														
Unidentified flatworms														
Nematoda														
Unidentified nematodes	654	2158	1046	1242	4837	1647	1810	305	611	382	114	305	344	179
Rhynchocoela														
Unidentified nemertean (red)	65	65	65	131	131	92	36	191	382	38	496	153	252	184
Unidentified nemertean (red w/white head)														
Phoronida														
Phoronopsis harmeri														
Chaetognatha														
Unidentified chaetognath								38	229	191	229	153	168	79
Gastropoda														
Acmaea sp. (Limpets)	196	196	654	261	65	274	224			38			8	17
Alvinia sp.														
Boreotrophon pacificus	131	65	38	196		86	78			229	38		53	100
Cylichna sp.			196	65	65	65	80							
Lacuna variegata	1307	458	327	392		497	486							
Littorina sitkana	588		327	2680	196	758	1095					38	8	17
Littorina scutulata								38				38	8	17
Moellaria sp.								38				38	15	21
Natica sp.												38	8	17
Nucella emarginata	65					13	29							
Odostomia sp.									38				8	17
Polinices pallidus														
Unidentified nudibranchs														
Bivalvia														
Clinocardium ciliatum								687	649	1336	992	1450	1023	366
Lucinoma annulata									38				8	17
Nuculana hamata								229	420	38	114	191	198	144
Nucula tenuis	1372	1307	1569	1634	1438	1464	136		229	305	496	267	260	178
Macoma balthica														
Macoma calcarea								153				38	38	66
Macoma nasuta														
Macoma obliqua														
Macoma sp.				65		13	29							
Mya arenaria				65		13	29							
Mya arenaria siphon	65			65	65	39	36							
Mysella sp.	1372	65	1307	327	1438	902	653							
Mytilus edulis														
Pandora filosa				65		13	29							
Panomya ampla	65		131	523	65	157	210							
Protothaca staminia								38					8	17
Psephidia lordi								76	38	38	38	38	46	17
Yoldia myalis														
Oligochaeta														
Oligochaetes				3006		601	1344					38	8	17
Polychaeta														
Ampharetidae sp. 1			65			13	29	38	114	76	76	114	84	32
Ampharetidae sp. 2	65					13	29							
Arabellidae								38	76	76			38	38
Aricidea jefreysii			65			13	29		38	76		76	38	38
Armandia brevis	131	654	588	1046	131	510	388	725	458	534	458	114	458	221
Capitellidae(unidentified juvenile)	654		1076	1046	915	738	445							
Capitellidae (short)										38			8	17
Chaetopteridae									191	114		153	92	88
Chaetozone setosa								611	1221	1221	1107	1679	1168	381
Chone sp.								38				76	23	34
Cossura longocirrata														
Dorvillea sp.	392	261	456	1176	523	562	357	38	76				23	34
Eteone longa														
Eunoe uniseriata								76					15	21
Euchone analis			196	392	65	131	167		38	38	153		46	68
Exogone gemmifera	6601	3399	8039	10458	4902	6680	2741			38	38		15	21
Fabricia sabella					65	13	29		76				15	34
Glycinde sp.								382	458	916	344	267	473	259
Gyptis sp.			131	65		39	68	611	534	114	38	496	359	262
Harmothoe imbricata								878	1145	611	1260	840	947	258
Haploscoloplos elongatus (Orbiniidae)		131				26	58	267	191		38	38	107	116
Lumbrineris sp.														
Maldanidae sp. 1														

CANNERY

	Intertidal							Subtidal						
	1	2	3	4	5	X̄	SD	1	2	3	4	5	X̄	SD
Nephtys ciliata	65	65	131			65	53	76	267	38		229	122	119
Nephtys sp. 1														
Nephtys sp. 2				65	65	26	36							
Nephtys sp. 3														
Nereidae		65				13	29							
Onuphis geophiliformis														
Owenia fusiformis		65				13	29							
Pectinaria sp.														
Pholoe minuta		65		131		39	58	649	229	458	267	229	366	184
Phyllodoce groenlandica											76		15	34
Pilargidae														
Polydora socialis		131		196	196	105	99					38	8	17
Praxillella sp.									114				23	51
Prionospio malmgreni			65		131	39	58					76	15	34
Prionospio (filament gills)								267	1260	496	458	344	565	399
Prionospio sp. (large eyes)														
Potamilla sp.														
Scolelepis sp.	65				65	26	36							
Sphaerosyllis erinaceus	65	65				26	36							
Sphaerosyllis sp.				65		13	29							
Spio filicornis	196	654	654	1242	1503	850	521							
Spiophanes sp.										38			8	17
Spionidae sp. 1 (forked nose)	458	523	261	654	719	523	179							
Spionidae sp. 2 (stubby nose)	196			261		92	127							
Spionidae sp. 3 (large eyes)														
Spionidae sp. 4 (black cheeks)														
Sternaspis scutata		65				13	29							
Syllis adamantea					65	13	29							
Syllis sp.		65	65			26	36							
Syllidae sp. 2			131	523	131	157	215							
Syllidae sp. 3														
Tharyx secundus				65		13	29	38	305	114	191	305	191	118
Travisia sp. 1														
Travisia sp. 2	196			980	65	248	417							
Archiannelida														
Dinophilidae														
Protodriloides sp.														
Amphipoda														
Bateidae														
Caprella laeviuscula														
Corophium sp. 1	1307					261	585							
Corophium sp. 2		3006	850	327	654	9067	1185							
Gammaridea sp.														
Hyperiidae sp.								114	76	153	114	76	107	32
Lysianassidae sp. 1														
Lysianassidae sp. 2														
Marinogammarus sp.														
Mesogammaridae														
Oedicerotidae sp. 1												76	15	34
Oedicerotidae sp. 2									114				23	51
Photis sp.														
Phoxocephalidae		65	65	131	392	131	153			38		38	8	17
Stenothoidae												38	8	17
Talitridae														
Unidentified amphipod sp. 2														
Unidentified amphipod sp. 3		65	65			26	36							
Unidentified amphipod sp. 4														
Cumacea														
Unidentified cumacean	1830	392	1895	850	2549	1503	868		38				8	17
Isopoda														
Asellota														
Gnorimosphaeroma oregonense			131		196	65	92							
Idotea aculatea														
Tanaidacea														
Unidentified tanaids														
Mysidacea														
Unidentified mysids														
Caridea														
Crangon munitella														
Sclerocrangon alata								38					8	17
Euphausiacea														
Unidentified euphausids								1145	1336	2099	1260	2290	1626	528
Copepods														
Cyclopiod copepod			1503	1307	784	719	707							
Unidentified Calanoid sp.			65			13	29	2290	2977	3321	1221	3702	2702	977
Unidentified Harpacticoid sp.	915	65	1046	1961	4248	1647	1602		38					

	CANNERY													
	Intertidal							Subtidal						
	1	2	3	4	5	$\overline{X}$	SD	1	2	3	4	5	$\overline{X}$	SD
Ostracod														
Unidentified ostracods														
Cirripedia														
Unidentified barnacles				64		13	29							
Paguroidea														
Pagurus sp.	65	196	523	588	719	413	276		38				8	17
Brachyura														
Unidentified crab								76	38	114	38	229	99	79
Unidentified zoea														
Arachnida														
Unidentified mite				65		13	29							
Unidentified Pseudoscorpionida														
Insecta														
Unidentified insect larvae	65		131		1111	261	478							
Unidentified species														
Echinodermata														
Unidentified sea urchins														
Unidentified sand dollars														
Unidentified sea cucumbers														
Unidentified star fish														
Tunicata														
Unidentified tunicates														

Table B-3. Number of macrobenthic organisms per m^2 by species in samples collected from the head of Hawk Inlet.

HEAD OF INLET

	Intertidal							Subtidal						
	1	2	3	4	5	$\bar{X}$	SD	1	2	3	4	5	$\bar{X}$	SD
Foraminifera														
Unidentified forams														
Cnidaria														
Unidentified anemones														
Platyhelminthes														
Acoela sp.	130					26	58							
Unidentified flatworms														
Nematoda														
Unidentified nematodes	130	130	260	130		130	92	76			305	76	92	125
Rhynchocoela														
Unidentified nemertean (red)	130					26	58	76	38	76	38	114	69	32
Unidentified nemertean (red w/white head)														
Phoronida														
Phoronopsis harmeri														
Chaetognatha														
Unidentified chaetognath														
Gastropoda														
Acmaea sp. (Limpets)														
Alvinia sp.								38		76	38	38	38	27
Boreotrophon pacificus														
Cylichna sp.														
Lacuna variegata	1558	1948	1558	5844	519	2285	2059	191	38	382	153	267	206	128
Littorina sitkana														
Littorina scutulata											763	611	275	380
Moellaria sp.	1688	4545	3247	1948	1039	2493	1400							
Natica sp.														
Nucella emarginata								38		76	38	38	38	27
Odostomia sp.														
Polinices pallidus														
Unidentified nudibranchs														
Bivalvia														
Clinocardium ciliatum											38		8	17
Lucinoma annulata								153			840	4008	1000	1717
Nuculana hamata														
Nucula tenuis											76	153	46	68
Macoma balthica	390	390	519	130	130	312	174							
Macoma calcarea														
Macoma nasuta		130		130		52	71	229		38	267	649	237	258
Macoma obliqua														
Macoma sp.														
Mya arenaria														
Mya arenaria siphon														
Mysella sp.	25714	19870	10519	13766	7662	15506	7292	191		229	4008	7443	2374	3293
Mytilus edulis		130				26	58							
Pandora filosa														
Panomya ampla														
Protothaca staminia														
Psephidia lordi														
Yoldia myalis														
Oligochaeta														
Oligochaetes														
Polychaeta														
Ampharetidae sp. 1														
Ampharetidae sp. 2														
Arabellidae														
Aricidea jefreysii									38		38		15	21
Armandia brevis											38		8	17
Capitellidae(unidentified juvenile)	1558	3766	2987	3117	390	2364	1366	76	114		573	305	214	230
Capitellidae (short)														
Chaetopteridae														
Chaetozone setosa														
Chone sp.												38	8	17
Cossura longocirrata												76	15	34
Dorvillea sp.											153	76	46	68
Eteone longa	260	1039	390	260	130	416	360					76	15	34
Eunoe uniseriata														
Euchone analis														
Exogone gemmifera														
Fabricia sabella				130		26	58							
Glycinde sp.	130		130	130	390	156	142	114		38	153	191	99	79
Gyptis sp.														
Harmothoe imbricata	130	779	390	519	390	442	236	305		420	649	76	290	262
Haploscoloplos elongatus(Orbiniidae)	390	2468	390	1299	390	987	917			3511	1260		954	1530
Lumbrineris sp.										38	1069	840	389	552
Maldanidae sp. 1														

HEAD OF INLET

	Intertidal							Subtidal						
	1	2	3	4	5	$\bar{X}$	SD	1	2	3	4	5	$\bar{X}$	SD
Nephtys ciliata	3636	7662	11169	2857	2727	5610	3705			38	611	267	183	264
Nephtys sp. 1		909	519	260	260	390	343				840	382	144	372
Nephtys sp. 2														
Nephtys sp. 3														
Nereidae														
Onuphis geophiliformis														
Owenia fusiformis														
Pectinaria sp.											38		8	17
Pholoe minuta								229		38	344	267	176	149
Phyllodoce groenlandica											38		8	17
Pilargidae				130		26	58	38				420	92	184
Polydora socialis														
Praxillella sp.						26	58				726	153		
Prionospio malmgreni	130									153	153	114	84	78
Prionospio sp. (filament gills)														
Prionospio sp. (large eyes)														
Potamilla sp.	649	649	519	649	390	571	116				76		15	34
Scolelepis sp.														
Sphaerosyllis erinaceus														
Sphaerosyllis sp.														
Spio filicornis	1169	1299	2338	1039	260	1221	744							
Spiophanes sp.		130				26	58							
Spionidae sp. 1 (forked nose)	11688	7792	12987	4545	2857	7974	4385				1298	191	298	565
Spionidae sp. 2 (stubby nose)			130			26	58							
Spionidae sp. 3 (large eyes)														
Spionidae sp. 4 (black cheeks)														
Sternaspis scutata														
Syllis adamantea														
Syllis sp.											38		8	17
Syllidae sp. 2	3636	5065	5195	647		2909	2449				38	38	15	21
Syllidae sp. 3														
Tharyx secundus														
Travisia sp. 1														
Travisia sp. 2	779	1429	2468	909	130	1143	873	38			229	114	76	97
Archiannelida														
Dinophilidae														
Protodriloides sp.														
Amphipoda														
Bateidae														
Caprella laeviuscula														
Corophium sp. 1														
Corophium sp. 2											38		8	17
Gammaridae														
Hyperiidae														
Lysianassidae sp. 1														
Lysianassidae sp. 2														
Marinogammarus sp.			390		260	130	184							
Mesogammaridae														
Oedicerotidae sp. 1														
Oedicerotidae sp. 2														
Photis sp.														
Phoxocephalidae														
Stenothoidae														
Talitridae											38		8	17
Unidentified amphipod sp. 2											38		8	17
Unidentified amphipod sp. 3		130				26	58			76			15	34
Unidentified amphipod sp. 4														
Cumacea														
Unidentified cumacean	130	260	260		130	156	109				76	114	38	54
Isopoda														
Asellota														
Gnorimosphaeroma oregonense														
Idotea aculatea														
Tanaidacea														
Unidentified tanaids	130					26	58							
Mysidacea														
Unidentified mysids	130	260	1688	779	4545	1480	1819							
Caridea														
Crangon munitella				130		26	58					38	8	17
Sclerocrangon alata														
Euphausiacea														
Unidentified euphausids														
Copepods														
Cyclopiod copepod														
Unidentified Calanoid sp.														
Unidentified Harpacticoid sp.	779	2597	8831	130		2467	3705				76	38	19	38

HEAD OF INLET

	Intertidal							Subtidal						
	1	2	3	4	5	$\bar{X}$	SD	1	2	3	4	5	$\bar{X}$	SD
Ostracod														
Unidentified ostracods		130	1039			234	454							
Cirripedia														
Unidentified barnacles														
Paguroidea														
Pagurus sp.				130		26	58							
Brachyura														
Unidentified crab														
Unidentified zoea														
Arachnida														
Unidentified mite														
Unidentified Pseudoscorpionida														
Insecta														
Unidentified insect larvae			130			26	58							
Unidentified species														
Echinodermata														
Unidentified sea urchins														
Unidentified sand dollars														
Unidentified sea cucumbers														
Unidentified star fish														
Tunicata														
Unidentified tunicates	130					26	58							

Table B-4. Number of macrobenthic organisms per m^2 by species in samples collected from a reference area south of the proposed docking facility in Young Bay.

SOUTHERN REFERENCE AREA

	Intertidal							Subtidal						
	1	2	3	4	5	X̄	SD	1	2	3	4	5	X̄	SD
								5844	13247	10520	7922		9383	3208
Foraminifera														
Unidentified forams														
Cnidaria														
Unidentified anemones														
Platyhelminthes														
Acoela sp.														
Unidentified flatworms														
Nematoda														
Unidentified nematodes	700	800	1600	1400		1375	479	779	260				260	367
Rhynchocoela														
Unidentified nemertean (red)	500	800	400	900		650	238	11039	5065	130	909		4286	4996
Unidentified nemertean (red w/white head)														
Phoronida														
Phoronopsis harmeri														
Chaetognatha														
Unidentified chaetognath														
Gastropoda														
Acmaea sp. (Limpets)	500	1300	1200	300		825	499				130		32	65
Alvinia sp.														
Boreotrophon pacificus														
Cylichna sp.														
Lacuna variegata								130					32	65
Littorina sitkana	1300	900	1800	600		1150	520							
Littorina scutulata										130			32	65
Moellaria sp.														
Natica sp.														
Nucella emarginata														
Odostomia sp.	100	300	300	200		225	96							
Polinices pallidus														
Unidentified nudibranchs														
Bivalvia														
Clinocardium ciliatum														
Lucinoma annulata														
Nuculana hamata														
Nucula tenuis														
Macoma balthica								2078	1429	520	779		1201	698
Macoma calcarea														
Macoma nasuta														
Macoma obliqua														
Macoma sp.														
Mya arenaria														
Mya arenaria siphon														
Mysella sp.	100					25	50	130					32	65
Mytilus edulis	2000	10500	4000	300		4200	4464				130		32	65
Pandora filosa														
Panomya ampla				100		25	50		130				32	65
Protothaca staminia	1000	1800	3000	1200		1750	900	3247	2338	1948	779		2078	1023
Psephidia lordi		200				50	100							
Yoldia myalis														
Oligochaeta														
Oligochaetes														
Polychaeta														
Ampharetidae sp. 1											130		32	65
Ampharetidae sp. 2														
Arabellidae														
Aricidea jefreysii														
Armandia brevis														
Capitellidae(unidentified juvenile)														
Capitellidae (short)														
Chaetopteridae														
Chaetozone setosa		100				25	50		260		260		130	150
Chone sp.														
Cossura longocirrata														
Dorvillea sp.														
Eteone longa														
Eunoe uniseriata														
Euchone analis														
Exogone gemmifera														
Fabricia sabella	100			200		75	96							
Glycinde sp.								260	390	260	260		292	65
Gyptis sp.														
Harmothoe imbricata														
Haploscoloplos elongatus (Orbiniidae)														
Lumbrineris sp.														
Maldanidae sp. 1														

SOUTHERN REFERENCE AREA

	Intertidal							Subtidal						
	1	2	3	4	5	X̄	SD	1	2	3	4	5	X̄	SD
Nephtys ciliata														
Nephtys sp. 1														
Nephtys sp. 2								130					32	65
Nephtys sp. 3											130		32	65
Nereidae														
Onuphis geophiliformis														
Owenia fusiformis														
Pectinaria sp.									130				32	65
Pholoe minuta														
Phyllodoce groenlandica														
Pilargidae														
Polydora socialis														
Praxillella sp.														
Prionospio malmgreni														
Prionospio sp. (filament gills)														
Prionospio sp. (large eyes)														
Potamilla sp.														
Scolelepis sp.														
Sphaerosyllis erinaceus														
Sphaerosyllis sp.														
Spio filicornis														
Spiophanes sp.								260	260		130		162	124
Spionidae sp. 1 (forked nose)														
Spionidae sp. 2 (stubby nose)														
Spionidae sp. 3 (large eyes)														
Spionidae sp. 4 (black cheeks)								130	130	130	260		162	65
Sternaspis scutata														
Syllis adamantea			200			50	100							
Syllis sp.														
Syllidae sp. 2	100					25	50							
Sillidae sp. 3														
Tharyx secundus														
Travisia sp. 1														
Travisia sp. 2	500	700	2500	2000		1425	978	130					32	65
Archiannelida														
Dinophilidae		200		500		175	236							
Protodriloides sp.	400					100	200				260		65	130
Amphipoda														
Bateidae														
Caprella laeviuscula														
Corophium sp. 1														
Corophium sp. 2														
Gammaridea sp.														
Hyperiidae sp.														
Lysianassidae sp. 1											260		65	130
Lysianassidae sp. 2														
Marinogammarus sp.									130	260	130		130	106
Mesogammaridae														
Oedicerotidae sp. 1														
Oedicerotidae sp. 2														
Photis sp.														
Phoxocephalidae														
Stenothoidae														
Talitridae														
Unidentified amphipod sp. 2														
Unidentified amphipod sp. 3														
Unidentified amphipod sp. 4														
Cumacea														
Unidentified cumacean		200	300	200		175	126			260			65	130
Isopoda														
Asellota														
Gnorimosphaeroma oregonense	18500	28300	24800	14600		21550	6157	130	130				65	75
Idotea aculatea														
Tanaidacea														
Unidentified tanaids														
Mysidacea														
Unidentified mysids														
Caridea														
Crangon munitella														
Sclerocrangon alata														
Euphausiacea														
Unidentified euphausids														
Copepods														
Cyclopiod copepod														
Unidentified Calanoid sp.	100					25	50	390	260	390	130		292	124
Unidentified Harpacticoid sp.			100	200		75	96	1688	390	1688	520		1071	714

SOUTHERN REFERENCE AREA

	Intertidal							Subtidal						
	1	2	3	4	5	$\overline{X}$	SD	1	2	3	4	5	$\overline{X}$	SD
Ostracod														
Unidentified ostracods	200					50	100		130				32	65
Cirripedia														
Unidentified barnacles	100	1400	300			450	646							
Paguroidea														
Pagurus sp.		100	100			50	58							
Brachyura														
Unidentified crab														
Unidentified zoea														
Arachnida														
Unidentified mite				200		50	100							
Unidentified Pseudoscorpionida														
Insecta														
Unidentified insect larvae		200	100	100		100	82							
Unidentified species														
Echinodermata														
Unidentified sea urchins														
Unidentified sand dollars														
Unidentified sea cucumbers														
Unidentified star fish														
Tunicata														
Unidentified tunicates														

Table B-5. Number of macrobenthic organisms per m^2 by species in samples collected for the proposed docking facilities in Young Bay.

DOCK SITE

	Intertidal							Subtidal						
	1	2	3	4	5	X̄	SD	1	2	3	4	5	X̄	SD
Foraminifera														
Unidentified forams														
Cnidaria														
Unidentified anemones														
Platyhelminthes														
Acoela sp.														
Unidentified flatworms														
Nematoda														
Unidentified nematodes		100				25	50							
Rhynchocoela														
Unidentified nemertean (red)	200	500	300	1000		500	356	130	130				87	75
Unidentified nemertean (red w/white head)														
Phoronida														
Phoronopsis harmeri														
Chaetognatha														
Unidentified chaetognath														
Gastropoda														
Acmaea sp. (Limpets)	100	800	200	700		450	351	130					43	75
Alvinia sp.														
Boreotrophon pacificus														
Cylichna sp.														
Lacuna variegata														
Littorina sitkana	100	200	200			125	96	130					43	75
Littorina scutulata														
Moellaria sp.														
Natica sp.														
Nucella emarginata														
Odostomia sp.														
Polinices pallidus														
Unidentified nudibranchs														
Bivalvia														
Clinocardium ciliatum														
Lucinoma annulata														
Nuculana hamata														
Nucula tenuis														
Macoma balthica														
Macoma calcarea														
Macoma nasuta														
Macoma obliqua														
Macoma sp.														
Mya arenaria														
Mya arenaria siphon														
Mysella sp.														
Mytilus edulis	25100	22100	2400	2500		13025	12272	130					43	75
Pandora filosa														
Panomya ampla	100	100				50	58							
Protothaca staminia								130	390	130			216	150
Psephidia lordi								130	130				87	75
Yoldia myalis														
Oligochaeta														
Oligochaetes														
Polychaeta														
Ampharetidae sp. 1														
Ampharetidae sp. 2								390	649	130			390	260
Arabellidae	300					75	150							
Aricidea jefreysii								1818	1429	1948			1732	270
Armandia brevis								130	130	130			130	0
Capitellidae(unidentified juvenile)														
Capitellidae (short)														
Chaetopteridae														
Chaetozone setosa								7922	7273	13896			9697	3651
Chone sp.														
Cossura longocirrata														
Dorvillea sp.														
Eteone longa		100				25	50			260			87	150
Eunoe uniseriata														
Euchone analis														
Exogone gemmifera														
Fabricia sabella	300		100	1100		375	499							
Glycinde sp.			100			25	50	260	520	649			216	375
Gyptis sp.														
Harmothoe imbricata														
Haploscoloplos elongatus (Orbiniidae)								130					43	75
Lumbrineris sp.														
Maldanidae sp. 1														

DOCK SITE

	Intertidal							Subtidal						
	1	2	3	4	5	X̄	SD	1	2	3	4	5	X̄	SD
Nephtys ciliata														
Nephtys sp. 1								1039	520				520	520
Nephtys sp. 2										1299			433	750
Nephtys sp. 3														
Nereidae								130					43	75
Onuphis geophiliformis														
Owenia fusiformis														
Pectinaria sp.								130	520				216	270
Pholoe minuta	800	100	200	100		300	337	260					87	150
Phyllodoce groenlandica														
Pilargidae														
Polydora socialis									130				43	75
Praxillella														
Prionospio malmgreni	100					25	50	130					43	75
Prionospio sp. (filament gills)														
Prionospio sp. (large eyes)														
Potamilla sp.														
Scolelepis sp.														
Sphaerosyllis erinaceus														
Sphaerosyllis sp.														
Spio filicornis														
Spiophanes sp.								1948	1169	2987			2035	912
Spionidae sp. 1 (forked nose)								260	130	260			216	75
Spionidae sp. 2 (stubby nose)														
Spionidae sp. 3 (large eyes)														
Spionidae sp. 4 (black cheeks)								1299	1948	1558			1602	327
Sternaspis scutata														
Syllis adamantea														
Syllis sp.														
Syllidae sp. 2														
Syllidae sp. 3														
Tharyx secundus														
Travisia sp. 1														
Travisia sp. 2		300	700		250	332								
Archiannelida														
Dinophilidae														
Protodriloides sp.				11500		2875	5750							
Amphipoda														
Bateidae														
Caprella laeviuscula														
Corophium sp. 1														
Corophium sp. 2														
Gammaridae sp.														
Hyperiidae sp.														
Lysianassidae sp. 1								5325	6104	6883			6104	779
Lysianassidae sp. 2														
Marinogammarus sp.				600		150	300							
Mesogammaridae														
Oedicerotidae #1														
Oedicerotidae #2														
Photis sp.														
Phoxocephalidae								260	130	260			216	75
Stenothoidae														
Talitridae														
Unidentified amphipod sp. 2	200					50	100	390					130	225
Unidentified amphipod sp. 3														
Unidentified amphipod sp. 4														
Cumacea														
Unidentified cumacean														
Isopoda														
Asellota														
Gnorimosphaeroma oregonense		100				25	50			130			43	75
Idotea aculatea														
Tanaidacea														
Unidentified tanaids														
Mysidacea														
Unidentified mysids														
Caridea														
Crangon munitella														
Sclerocrangon alata														
Euphausiacea														
Unidentified euphausids														
Copepods														
Cyclopiod copepod														
Unidentified Calanoid sp.								260		130			130	130
Unidentified Harpacticoid sp.														

DOCK SITE

	Intertidal							Subtidal						
	1	2	3	4	5	$\bar{X}$	SD	1	2	3	4	5	$\bar{X}$	SD
Ostracod														
Unidentified ostracods														
Cirripedia														
Unidentified barnacles	3800	8100	4400	7400		5925	2141							
Paguroidea														
Pagarus sp.				400		100	200							
Brachyura														
Unidentified crab														
Unidentified zoea														
Arachnida														
Unidentified mite	200			300		125	150							
Unidentified Pseudoscorpionida		100				25	50							
Insecta														
Unidentified insect larvae	300	100		500		225	222							
Unidentified species														
Echinodermata														
Unidentified sea urchins														
Unidentified sand dollars														
Unidentified sea cucumbers														
Unidentified star fish														
Tunicata														
Unidentified tunicates														

Table B-6. Number of macrobenthic organisms per m^2 by species in samples collected from a reference area north of the proposed docking facility in Young Bay.

NORTHERN REFERENCE AREA

	Intertidal							Subtidal						
	1	2	3	4	5	X̄	SD	1	2	3	4	5	X̄	SD
Foraminifera														
Unidentified forams														
Cnidaria														
Unidentified anemones														
Platyhelminthes														
Acoela sp.	100			100		50	58							
Unidentified flatworms														
Nematoda														
Unidentified nematodes	300	1300	400	17090		925	685		130				32	65
Rhynchocoela														
Unidentified nemertean (red)			100	200		75	96	260	130	103			130	106
Unidentified nemertean (red w/white head)														
Phoronida														
Phoronopsis harmeri														
Chaetognatha														
Unidentified chaetognath														
Gastropoda														
Acmaea sp. (Limpets)														
Alvinia sp.														
Boreotrophon pacificus														
Cylichna sp.		300		200		125	150							
Lacuna variegata	300		500	100		225	222							
Littorina sitkana														
Littorina scutulata														
Moellaria sp.														
Natica sp.														
Nucella emarginata														
Odostomia sp.														
Polinices pallidus														
Unidentified nudibranchs														
Bivalvia														
Clinocardium ciliatum														
Lucinoma annulata														
Nuculana hamata														
Nucula tenuis														
Macoma balthica														
Macoma calcarea														
Macoma nasuta														
Macoma obliqua														
Macoma sp.														
Mya arenaria										130			32	65
Mya arenaria siphon														
Mysella sp.	100	400	200	500		300	183	130		130	130		97	65
Mytilus edulis											130		32	65
Pandora filosa								520	260	130	649		390	237
Panomya ampla											130		32	65
Protothaca staminia														
Psephidia lordi														
Yoldia myalis														
Oligochaeta														
Oligochaetes									390	260			162	195
Polychaeta														
Ampharetidae sp. 1								130			260		97	124
Ampharetidae sp. 2								649	520	260	649		520	184
Arabellidae								649	390				260	318
Aricidea jefreysii														
Armandia brevis														
Capitellidae(unidentified juvenile)														
Capitellidae (short)								17403	7143	7662	12468		1169	4798
Chaetopteridae														
Chaetozone setosa														
Chone sp.														
Cossura longocirrata									130				32	65
Dorvillea sp.														
Eteone longa														
Eunoe uriseriata										130			32	65
Euchone analis														
Exogone gemmifera			100			25	50		260	260	649		292	268
Fabricia sabella														
Glycinde sp.														
Gyptis sp.								130		130	260		130	106
Harmothoe imbricata								130			130		65	75
Haploscoloplos elongatus (Orbiniidae)														
Lumbrineris sp.														

NORTHERN REFERENCE AREA

	Intertidal							Subtidal						
	1	2	3	4	5	X̄	SD	1	2	3	4	5	X̄	SD
Nephtys ciliata														
Nephtys sp. 1									260	520			195	249
Nephtys sp. 2								520			260		195	249
Nephtys sp. 3														
Nereidae														
Onuphis geophiliformis														
Owenia fusiformis														
Pectinaria sp.								130	390	130	390		260	150
Pholoe minuta														
Phyllodoce groenlandica														
Pilargidae														
Polydora socialis									260				65	130
Praxillella sp.														
Prionospio malmgreni														
Prionospio sp. (filament gills)														
Prionospio sp. (large eyes)								520	130				162	246
Potamilla sp.														
Scolelepis sp.														
Sphaerosyllis erinaceus														
Sphaerosyllis sp.														
Spio filicornis														
Spiophanes sp.		200				50	100	1169	390	909	2208		1169	765
Spionidae sp. 1 (forked nose)								260	130	260	390		260	106
Spionidae sp. 2 (stubby nose)														
Spionidae sp. 3 (large eyes)														
Spionidae sp. 4 (black cheeks)								3247	2857	2727	2078		2729	486
Sternaspis scutata		100	100			50	58							
Syllis adamantea														
Syllis sp.														
Syllidae sp. 2		100		200		75	96							
Syllidae sp. 3														
Tharyx secundus														
Travisia sp. 1														
Travisia sp. 2	900	1500	900	2600		1475	802				130		32	65
Archiannelida														
Dinophilidae		100				25	50							
Protodriloides sp.														
Amphipoda														
Bateidae														
Caprella laeviuscula														
Corophium sp. 1														
Corophium sp. 2														
Gammaridea sp.														
Hyperiidae sp.														
Lysianassidae sp. 1								3896	3377	2857	1688		2954	945
Lysianassidae sp. 2														
Marinogammarus sp.								130	130				65	75
Mesogammaridae														
Oedicerotidae sp. 1														
Oedicerotidae sp. 2														
Photis sp.														
Phoxocephalidae									130				32	65
Stenothoidae														
Talitridae														
Unidentified amphipod sp. 2								130					32	65
Unidentified amphipod sp. 3														
Unidentified amphipod sp. 4														
Cumacea														
Unidentified cumacean														
Isopoda														
Asellota														
Gnorimosphaeroma oregonense														
Idotea aculatea														
Tanaidacea								130					32	65
Unidentified tanaids														
Mysidacea														
Unidentified mysids														
Caridea														
Crangon munitella														
Sclerocrangon alata														
Euphausiacea														
Unidentified euphausids											130		32	65
Copepods														
Cyclopiod copepod														
Unidentified Calanoid sp.	200		200	200		150	100	260	130	390	260		260	106
Unidentified Harpacticoid sp.											130		32	65

NORTHERN REFERENCE AREA

	Intertidal							Subtidal						
	1	2	3	4	5	$\bar{X}$	SD	1	2	3	4	5	$\bar{X}$	SD
Ostracod														
Unidentified ostracods		100		100		50	58							
Cirripedia														
Unidentified barnacles		500		500		250	289							
Paguroidea														
Pagurus sp.														
Brachyura														
Unidentified crab														
Unidentified zoea														
Arachnida														
Unidentified mite														
Unidentified Pseudoscorpionida														
Insecta														
Unidentified insect larvae				300		75	150							
Unidentified species														
Echinodermata														
Unidentified sea urchins														
Unidentified sand dollars														
Unidentified sea cucumbers														
Unidentified star fish														
Tunicata														
Unidentified tunicates														

APPENDIX C

BIOGRAPHIES OF AUTHORS

A. FREDERICK HOLLAND
Scientist
Environmental Center

Education

B.S., Biology, The Citadel, 1964
M.S., Biology, University of South Carolina, 1972
Ph.D., Marine Science, University of South Carolina, 1974

Professional Background

Dr. Holland joined Martin Marietta's Environmental Center in 1974 as a Research Scientist. He has been responsible for designing, conducting, and coordinating studies to identify and quantify effects of perturbation on the structure and function of benthic communities. Dr. Holland has conducted extensive field research on organism-sediment relations and on factors affecting benthic community structure and population dynamics of benthic organisms. A special research interest is determining the importance of physical and biological factors in controlling benthic community structure and function by studying effects of these factors on population dynamics of dominant species. His present research efforts have been in the area of benthic-pelagic coupling and long-term variation in benthic communities. He is presently conducting studies to evaluate changes in benthic communities due to salinity, perturbation, and organic enrichment, and to describe long-term trends in the abundance of major benthic species. These studies involve intensive investigation and characterization of the population dynamics of representative benthic species. He has studied important aspects of the population dynamics, energetics biogeography, and systematics of ecologically important invertebrate species.

MARTHA H. HIEGEL
R&D Specialist
Environmental Center

Education

B.S., Zoology, Louisiana State University, 1969
M.S., Zoology, Louisiana State University, 1971

Professional Background

Ms. Martha H. Hiegel has been a technical assistant on benthic field programs since 1975. She is a recognized authority on the identification of benthic invertebrates and on methods of collecting and processing of benthic samples. She is presently responsible for ensuring that benthic samples collected by EC's ongoing benthic programs are processed in a timely manner. Ms. Hiegel's experience with the mechanics of benthic field projects has provided her with a broad background in the general area of benthic ecology. She has been responsible for collecting and processing sediment samples; has used a broad variety of benthic sampling devices and processing methods; has participated in field experiments on predator exclusion, organic enrichment, and recolonization; has collected and processed ATP samples to estimate microbenthic standing stocks; and has processed meiobenthic and macrobenthic samples. She is a recognized biological illustrator who has published illustrations of benthic organisms in a number of books and journals. Ms. Hiegel has also conducted studies on the population dynamics of several bivalves.

WILLIAM A. RICHKUS
Senior Scientist and Technical Director
Environmental Center

Education

B.S., Zoology, University of Rhode Island, 1966
M.S., Oceanography, University of California (San Diego)
Scripps Institute of Oceanography, 1968
Ph.D., Oceanography, Graduate School of Oceanography, University of Rhode Island, 1974

Professional Background

Dr. Richkus has been a staff member of Martin Marietta's Environmental Center since June 1974, participating in studies aimed at identifying and quantifying the effects of power plant operations on fish stocks in the Chesapeake Bay and its tributaries. He has also participated in assessments of impacts of various Corporate facilities. He has prepared and assisted in the preparation of numerous documents for state and federal agencies, technical audiences, and the general public.

Dr. Richkus has recently served as program manager and co-principal investigator on a Maryland Coastal Resources Division project to evaluate the suitability and applicability of fisheries population and yield models for the management of Maryland tidewater fisheries. He is also currently directing field and laboratory work designed to assess levels of heavy metals in the tissues of various freshwater and marine biota.

Dr. Richkus currently directs studies funded by the Maryland Department of Natural Resources to assess environmental impacts of the Conowingo hydroelectric facility on the Susquehanna River. Ongoing studies are aimed at assessing the effects of the facility on water quality, aquatic biota, and commercial and recreational fisheries resources, and possible mitigation measures necessary to alleviate measured impacts. Dr. Richkus also currently serves as technical advisor and expert witness for the State of Maryland in ongoing FERC proceedings relating to restoration of anadromous fish runs in the Susquehanna River drainage. In this role, he has assisted all other intervening parties in preparation of the case, including U.S. Fish and Wildlife Service, Susquehanna River Basin Commission, and other state and citizens groups.

MARTIN MARIETTA

The History of Greens Creek Exploration

By Andrew W. West

Chapter 3 of

Geology, Geochemistry, and Genesis of the Greens Creek Massive Sulfide Deposit, Admiralty Island, Southeastern Alaska

Edited by Cliff D. Taylor and Craig A. Johnson

Professional Paper 1763

U.S. Department of the Interior
U.S. Geological Survey

Contents

Figures

The History of Greens Creek Exploration[1]

By Andrew W. West

Abstract

The exploration history of the Greens Creek mine and district includes not only battles fought on the steep and intimidating terrain of Admiralty Island, but also in Washington, D.C., and the Oval Office of the White House. The Greens Creek mine is unique in that it is completely enclosed within a national monument. The time period that began with the initial discovery, in 1974, of the "Big Sore" ore suboutcropping and ended with the underground definition drilling of the orebody, overlapped with the largest national conservation movement of this century that ultimately led to congressional approval of Alaska National Interest Land Claims Act (ANILCA) in 1980. Not only did this legislative act have a profound effect on the subsequent exploration of the district and eventual production of Greens Creek, ANILCA shaped the economic life of Alaska as a whole.

Introduction

The Greens Creek mine (fig. 1) went from initial discovery to predevelopment and production in a fairly orderly, yet untimely manner. The Pan-Sound Joint Venture (JV), charged with mineral exploration in southeast Alaska in 1973, intersected ore in the very first "discovery" drill hole in 1975. The timeline for the project, which is shown in figure 2, demonstrates that despite nearly continuous exploration and(or) predevelopment work, production did not begin until February 1989. During this 16-year period, many changes occurred both within and between the joint venture partners. The conservation movement in the late 1970s also had a huge effect on the Greens Creek project, culminating in the passage of the Alaska National Interest Lands Conservation Act (ANILCA) in 1980. Exploration during the first years of production was successful in increasing reserves; however declining metal prices precipitated a shutdown of production in April 1993. Exploration and definition drilling of the higher grade Southwest Ore Zone from 1993 to 1994 resulted in a new feasibility study that was accepted by the joint venture partners, Kennecott Minerals and Hecla Mining. The mine reopened in 1996. National legislation reentered the picture when President Clinton signed the Land Exchange Bill in August of 1996. This unique piece of legislation allows for exploration and grants subsurface mineral rights to much of what was the original unpatented claim block that existed prior to ANILCA. The 7,301 acres of prospective ground allows Greens Creek to continue exploration activities aimed at increasing the life of the mine.

Pan Sound Joint Venture, 1973–78

The Pan Sound Joint Venture was formed in 1973 as a grass-roots exploration program to find base and(or) precious metal deposits in the northern part of southeast Alaska, the Prince William Sound area, and the Kenai Peninsula. The original partners were Noranda Exploration (29.73 percent), Marietta Resources (29.73 percent), Exhalas Resources (29.73 percent), and Texas Gas Exploration (10.81 percent). The rationale behind the exploration program in Alaska was fourfold: (1) exploration was risky in other parts of the world due to unfavorable politics; (2) exploration opportunities in the rest of North America were dwindling; (3) the geology of Alaska was seen as being highly favorable for economic deposits; and (4) the ongoing national energy crisis was underscoring the importance of a healthy domestic natural resource industry (L.M. Klingmueller and G.G. Bigelow, Watts, Griffis and McQuat, Inc., written commun., 1973). Watts, Griffis and McQuat (WGM) of Anchorage was contracted by the Pan Sound JV to carry out an extensive stream silt-sampling project in southeast Alaska. Their 1973 survey yielded anomalous zinc and copper stream silt samples collected from Cliff Creek (east of Big Sore Creek) and just southeast of Hawk Inlet (fig. 1). The sample from Cliff Creek contained 0.13 percent zinc and appeared to be associated with mineralized (disseminated pyrite and chalcopyrite) float from the Triassic Hyd basalt that forms the major cliff above Cliff Creek. Inclement weather prevented any followup work, but an intensive followup survey was recommended for the Cliff Creek drainage as well as first-pass coverage of the areas north and south of Greens Creek. WGM did not stake any claims in the Greens Creek area.

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[1] Much of the information conveyed in this chapter was first documented in memoranda or reports to Kennecott Greens Creek Mining Company or its antecedents. Because they are unavailable to the public, these documents are cited in text only.

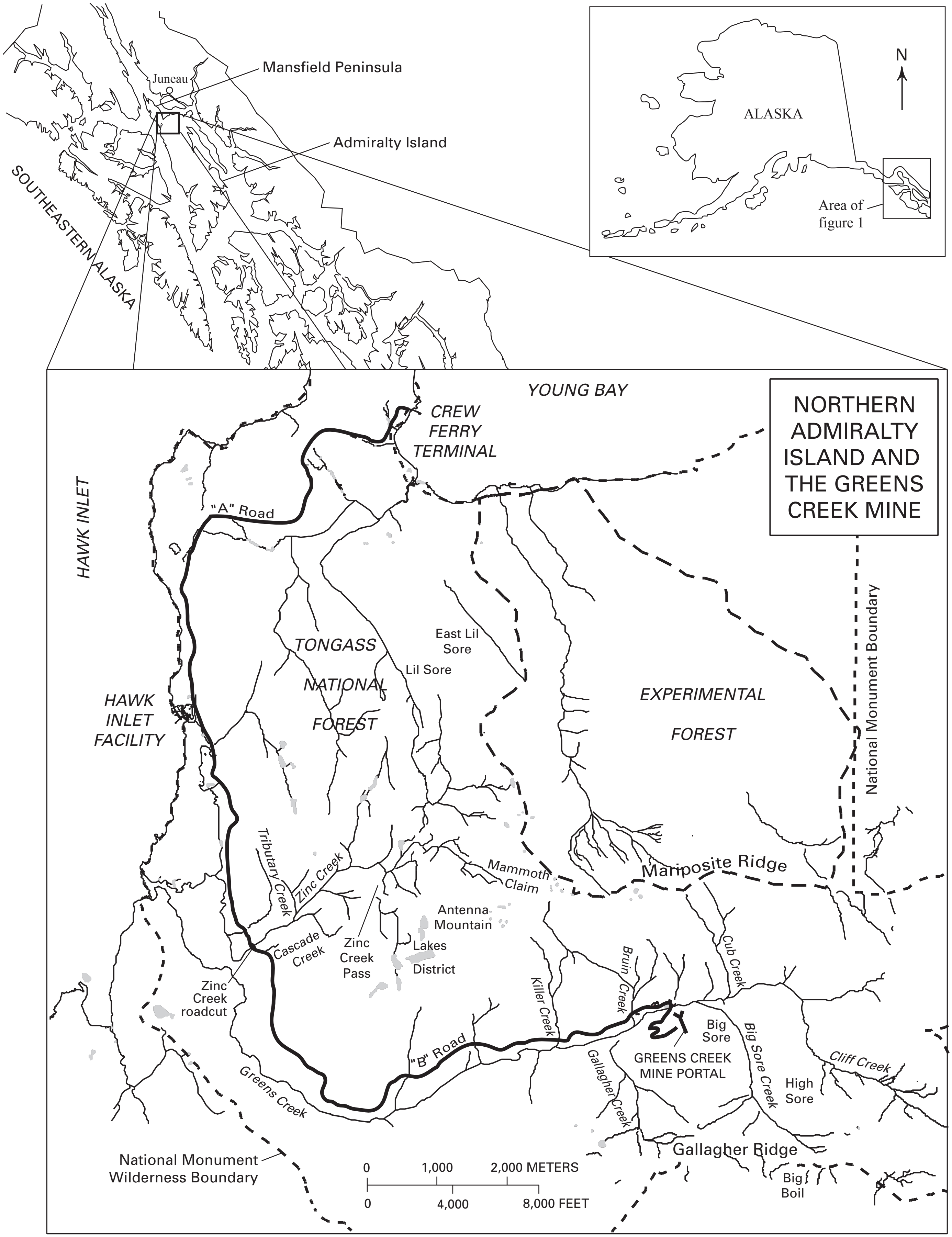
Juneau
Mansfield Peninsula
Admiralty Island
SOUTHEASTERN ALASKA
N
ALASKA
Area of figure 1
NORTHERN ADMIRALTY ISLAND AND THE GREENS CREEK MINE
YOUNG BAY
CREW FERRY TERMINAL
HAWK INLET
"A" Road
TONGASS NATIONAL FOREST
East Lil Sore
Lil Sore
EXPERIMENTAL FOREST
HAWK INLET FACILITY
National Monument Boundary
Tributary Creek
Zinc Creek
Mammoth Claim
Mariposite Ridge
Antenna Mountain
Cascade Creek
Zinc Creek Pass
Lakes District
Zinc Creek roadcut
Killer Creek
Bruin Creek
Cub Creek
Big Sore
Big Sore Creek
GREENS CREEK MINE PORTAL
"B" Road
Gallagher Creek
Cliff Creek
High Sore
Greens Creek
Gallagher Ridge
National Monument Wilderness Boundary
0
1,000
2,000 METERS
0
4,000
8,000 FEET
Big Boil

Figure 1 (facing page). Map of northern Admiralty Island showing the Greens Creek mine and other localities discussed in the text.

WGM geologists Bill "Boomer" Block and Joe Dreschler discovered the Greens Creek orebody in 1974 when they observed a large ferricrete kill zone from the air during the followup program (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1975). Dubbed the "Big Sore," this area (fig. 1) quickly became the focal point of exploration. A soil geochemistry grid laid out over the Big Sore delineated numerous silver-zinc anomalies on the order of 100 parts per million (ppm) silver and up to 1.7 percent zinc. WGM completed a Crone shootback electromagnetic (CEM) geophysical survey over 19,800 feet of gridline and a surface magnetometer survey totaling 12,500 feet. The CEM survey detected a partial conductor roughly coincident with soil anomalies. Two magnetic highs were identified in the lower reaches of Killer Creek. The WGM geologists postulated that the source of the CEM conductor was a mapped graphitic quartz-mica schist (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1975). The magnetic anomalies were due to magnetite-bearing sulfide layers discovered in Killer Creek. A float sample believed to be from the same unit assayed for more than 10 percent copper. These two items generated additional interest in Killer Creek. Most of the exposed mineralization found by WGM, other than the Big Sore itself, was from the Killer Creek area.

WGM staked 134 lode claims, named the Big Sore claims, to establish the land position. The claims stretched from the southeast corner of Cliff Creek across the Greens Creek valley to the northeast corner of Upper Zinc Creek. WGM suggested that the land on the north, east, and south sides also be staked. There was concern that the large claim block would attract attention from various competitors (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1975). Until 1974, very little competitor activity was noted for Admiralty Island except for a small backpack-supported survey of Northern Chicagof and Admiralty Islands by Placid Oil. Also, Resource Associates of Alaska (RAA) and Urangellschaft were exploring parts of Northern Admiralty Island.

The 1974 exploration results led WGM and the Pan Sound JV to believe that the "strongest reconnaissance potential for the discovery of a stratabound massive sulfide is considered to be within the Paleozoic schists located north and south of the Greens Creek discoveries on Admiralty Island" (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1975). WGM recommended additional soil sampling, extension of the CEM survey, detailed geologic mapping, and diamond drill testing of the main Big Sore anomaly. They believed that the Big Sore and Killer Creek areas had the potential to host one or more copper-lead-zinc sulfide body(s) of unknown grade with greater than 1,000 feet of strike length.

1975 Program

The Big Sore project and a detailed reconnaissance of Admiralty Island were two of three projects that the 1975 Pan Sound JV undertook. The third project was followup work on a copper prospect of Latouche Island in Prince William Sound. The 1975 Big Sore project was the most ambitious thus far with more than 1,000 soil, rock, and stream silt samples taken; 80,000 feet of CEM and magnetometer surveys; initial detailed geologic mapping; and trenching and blasting to outline drill targets. Diamond drilling also commenced with three holes completed before the end of the field season. The Big Sore project began on June 4 with a camp at Big Sore Creek. The project demobilized on September 20 when the drilling program finished.

Results from expanding the Big Sore soil grid led the WGM geologists to believe that the stratabound mineralization occurred along three to five stratigraphic horizons within Devonian units (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1976). They believed that soil sampling was the best tool to establish drill targets because of the thick glacier till, the vegetation cover, and the difficulty in defining the stratigraphy. However, WGM did not associate the geochemical and electromagnetic (EM) signatures with a chlorite-carbonate-schist and graphitic schist contact (determined later to be the mineralized horizon).

The three completed diamond drill holes totaled 997 feet. The first drillhole, DDH–1 (later renamed PS–1), was drilled about 150 feet above the Big Sore to test the high-order soil anomaly and the coincident CEM anomaly. The "discovery" hole intersected 89 feet of continuous pyrite and base-metal massive sulfide beginning at 138 feet downhole. This hole remains the longest continuous intersection of massive sulfide mineralization drilled from the surface at Greens Creek. The interval averaged 0.123 troy ounce per ton gold, 5.77 troy ounces per ton silver, 2.04 percent lead, 8.03 percent zinc, and 0.43 percent copper. A marked increase in pyrite and decrease in chlorite-muscovite near the massive sulfide interval was noted. The hole terminated at 296 feet in dolomitic graphite-quartz-mica schist, with local bands of massive sulfide. Holes DDH–1 and DDH–2 were both lost due to caving ground, a harbinger for drilling problems to come. Hole DDH–1 was not able to test the two lower targets identified from the soil sampling.

Hole DDH–2 (PS–2) was collared about 500 feet to the south-southeast of hole DDH–1, downhill from the graphite schist contact. The hole intersected graphitic schist with two massive sulfide bands containing 4.86 percent zinc and 4.3 troy ounces per ton silver over 12 feet, and 6.32 percent zinc, 7.2 troy ounces per ton silver, and 0.275 troy ounce per ton gold over 29.5 feet. The hole was lost due to poor ground conditions before it reached its target horizon. DDH–3 (PS–3) was collared 200 feet downhill from DDH–2 to test the previously untested lower soil anomaly. No visible base-metal sulfides were intersected to the termination depth of 635 feet, despite the presence of "fresh" massive sulfide float and high multi-element soil values directly below the hole.

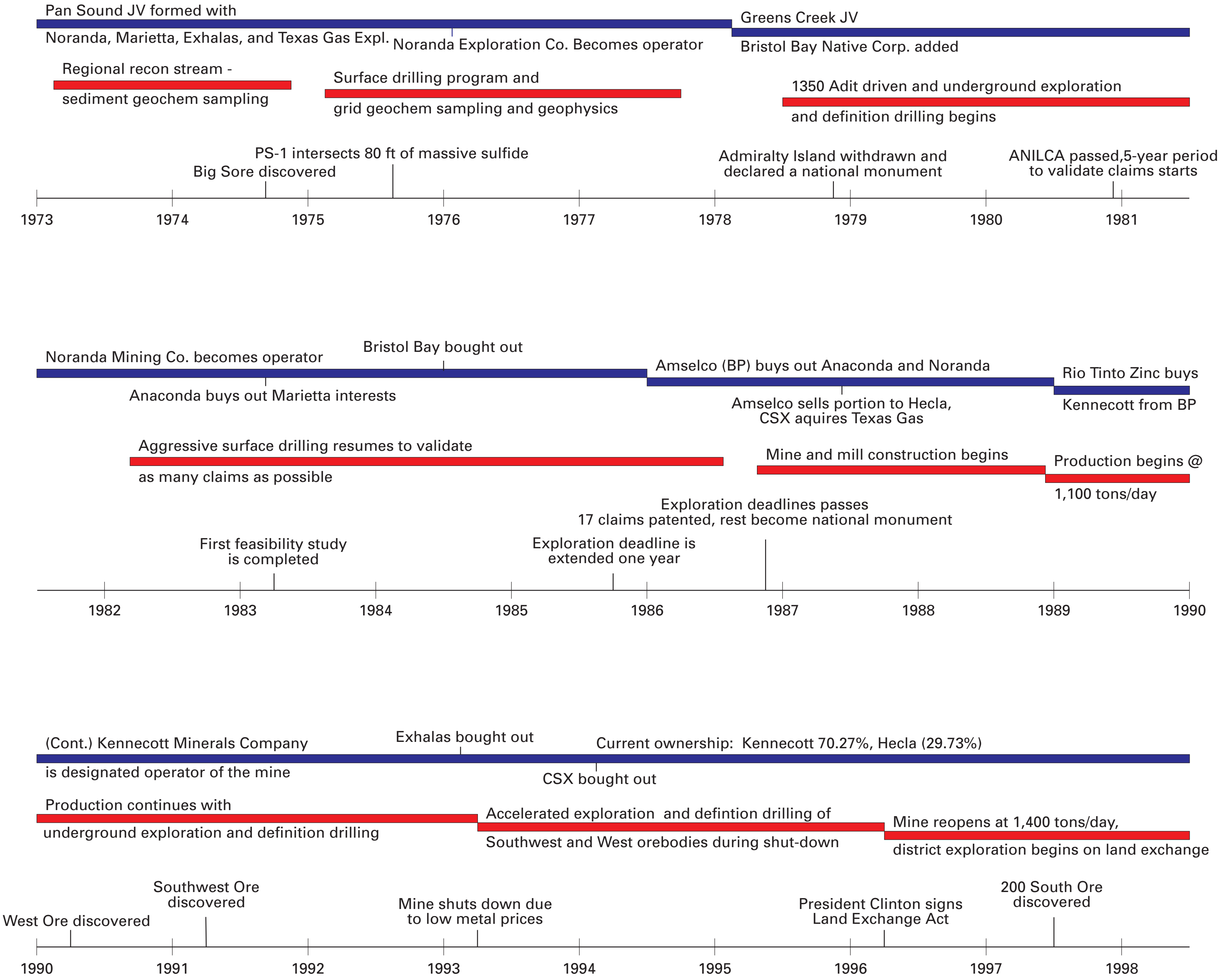
Pan Sound JV formed with
Noranda, Marietta, Exhalas, and Texas Gas Expl.
Noranda Exploration Co. Becomes operator
Greens Creek JV
Bristol Bay Native Corp. added
Regional recon stream -
sediment geochem sampling
Surface drilling program and
grid geochem sampling and geophysics
1350 Adit driven and underground exploration
and definition drilling begins
PS-1 intersects 80 ft of massive sulfide
Big Sore discovered
Admiralty Island withdrawn and
declared a national monument
ANILCA passed,5-year period
to validate claims starts
1973
1974
1975
1976
1977
1978
1979
1980
1981
Noranda Mining Co. becomes operator
Bristol Bay bought out
Anaconda buys out Marietta interests
Amselco (BP) buys out Anaconda and Noranda
Amselco sells portion to Hecla,
CSX aquires Texas Gas
Rio Tinto Zinc buys
Kennecott from BP
Aggressive surface drilling resumes to validate
as many claims as possible
Mine and mill construction begins
Production begins @
1,100 tons/day
Exploration deadlines passes
17 claims patented, rest become national monument
First feasibility study
is completed
Exploration deadline is
extended one year
1982
1983
1984
1985
1986
1987
1988
1989
1990
(Cont.) Kennecott Minerals Company
is designated operator of the mine
Exhalas bought out
Current ownership: Kennecott 70.27%, Hecla (29.73%)
CSX bought out
Production continues with
underground exploration and definition drilling
Accelerated exploration and defintion drilling of
Southwest and West orebodies during shut-down
Mine reopens at 1,400 tons/day,
district exploration begins on land exchange
Southwest Ore
discovered
West Ore discovered
Mine shuts down due
to low metal prices
President Clinton signs
Land Exchange Act
200 South Ore
discovered
1990
1991
1992
1993
1994
1995
1996
1997
1998

Figure 2 (facing page). Ownership (blue) and exploration (red) timeline.

Correlation of the above drill holes and soil anomalies led the WGM geologists to believe there were at least four, and maybe more, separate mineralized horizons to target (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1976). DDH–3 displayed wildly fluctuating foliation orientations, but folding of the mineralized horizon was not considered. Using the drill-hole results and a tonnage factor of 12, WGM estimated an inferred metal "inventory" of 2 to 20 million tons of greater than 1.5 percent lead, 6.0 percent zinc, 0.1 troy ounce per ton gold, and 6.0 troy ounces per ton silver (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1976). WGM recommended an aggressive (>10,00-foot) drilling program to rapidly bring the Big Sore Prospect to a development decision. They believed that the 1976 drilling program would place the inventory into "exploration" or "possible" reserves category, "barring unusual structural, facies complexity, or external factors" (T.E. Andrews and C. Bigelow, Watts, Griffis and McQuat, Inc., written commun., 1975).

Exploration work was also carried out in the Gallagher Creek, Killer Creek, and North Ridge (Mariposite Ridge) areas (fig. 1). Highlights include the discovery of massive sulfide float and outcrops in Gallagher Creek containing up to 31 percent zinc and 2.1 troy ounces per ton silver (T.E. Andrews and C. Bigelow, Watts, Griffis and McQuat, Inc., written commun., 1976). The outcrops contain sulfide veins up to 2 inches wide over a mineralized interval approximately 100 feet thick. Various mineralization styles were described, sampled, and mapped from the North Ridge, mostly in the vicinity of the Mammoth claims (see next paragraph). "Impressive" values were returned for gold, silver, lead, and zinc. Preliminary sampling and mapping did not provide sufficient data to determine the structural or stratigraphic setting of the mineralization.

The land status was further enhanced surrounding the Big Sore prospect during 1975. An additional 150 claims were added to the Big Sore claim group in all directions. The claim block was extended to the north, overlapping the four patented Mammoth claims that were originally staked in 1889 and patented in 1915. The overlapping claims were not to "jump" the existing claims but to ensure no area was left open between the two claim groups (fig. 1) (T.E. Andrews and C. Bigelow, Watts, Griffis and McQuat, Inc., written commun., 1975). An abandoned adit exists on the Mammoth claim that was excavated about 1904 along a massive galena-sphalerite band. WGM suggested that the owner, Herman Meiners of Juneau, be approached to see if the property could be leased or bought outright before the increased activity at Greens Creek increased the asking price.

The separate reconnaissance program of Admiralty Island completed much of its work near Greens Creek. The Tom claims were staked (a total of 52) to the east of Hawk Inlet within the lower Greens Creek and Zinc Creek drainages (T.E. Andrews and C. Bigelow, Watts, Griffis and McQuat, Inc., written commun., 1976). WGM sampled Big Sore-type mineralization in graphitic quartz-mica schist, greenstones, and quartz-chlorite-carbonate schists with mariposite. In addition, work was done near ferricrete "sores" in a prospect named Kit Creek (now Lil Sore, fig. 1). The north-northwest-trending sores that contain up to 9,500 ppm zinc were postulated as representing a stratabound zinc sulfide body at moderate depth cut by permeable faults or fractures. No claims were staked during the field season because the land was nominated for Native Selection but was later withdrawn. Other prospects or claims explored included the Scull, Eagle Peak, and Jimbo to the northeast of Greens Creek, the Wheeler and Pyrola to the south and southwest of Greens Creek, and the JS and Barron on Mansfield Peninsula. As a result of the reconnaissance program, 472 new claims were staked on these new prospects. The Big Sore prospect was the standard with which the other prospects were compared, based on type of mineralization present and similar stratigraphy.

1976 Program

Noranda became the operator of the Big Sore program in 1976 for the Pan Sound JV. The program was composed of two projects again, one project concentrating on continued reconnaissance of Northern Admiralty Island, looking for other Greens Creek-type targets, while the other project continued exploration on the Big Sore and Tom claims. The principal objectives at Big Sore were to define the extent of the mineralized horizon intersected in DDH–1 and determine the geologic and geochemical nature of the mineralized zone (John Dunbier, Noranda Exploration, Inc., written commun., 1976). A geochemical grid with CEM and magnetic surveys was oriented north to south along Gallagher and Killer Creeks. The existing grid system was reoriented to trend N. 30° W. and center the baseline on the discovery hole. Two drill rigs were used for the program. A Longyear-34 hydraulic drill rig operated by Diamond Drill Contractors completed the deeper holes. A much smaller Winkie drill, owned and operated by Noranda, drilled 1.197-inch-diameter (AQ) core to penetrate the overburden and determine the lithology of the bedrock in areas of no outcrop. An additional 400+ claims were staked to fill in the gap between the Tom and Big Sore claims.

The diamond drilling program was successful in extending the known mineralized zone to the south-southeast, north-northwest, and slightly downdip (John Dunbier, Noranda Exploration, Inc., written commun., 1976). Three of the five holes drilled with the Longyear-34 intersected low- to high-grade ore along the contact between sericite-quartz phyllite (identified as "tuffites") and the graphitic schist unit. The other two holes intersected minor mineralization in the tuffites (the hanging wall). Hole PS–3–76 intersected 11 feet of 0.042 troy ounce per ton gold, 22.7 troy ounces per ton silver, 5.9 percent lead, and 14.6 percent zinc to extend the known mineralized zone about 300 feet to the south-southeast of the discovery hole. PS–4–76 intersected a lower grade, yet thicker 12-foot interval grading 9.9 troy ounces per ton silver and 3.45 percent zinc about 320 feet to the north-northwest. PS–7–76 extended the envelope even farther to the north-northwest (600 feet) with a 6-foot intercept of 29.3 troy ounces per ton silver and only 1.7 percent zinc.

The Winkie drill program consisted of eight holes. Only two of the holes intersected mineralization within the hanging-wall rocks while testing soil anomalies to the northwest of PS–1. One hole, PSW–4, was later followed up by hole PS–7–76 (mentioned previously). Two of the holes were unable to penetrate the overburden. Two large-diameter holes and one Winkie drill hole were drilled in Gallagher Creek. PS–1–76 and PS–2–76 intersected only minor mineralization of up to 4.4 percent zinc over 5 feet.

Noranda Exploration initiated a geologic mapping project carried out by one of their geologists, M.D. Bingham. Noranda anticipated taking a more active role in the Big Sore prospect and wanted to gain firsthand familiarity of the project (M.D. Bingham, Noranda Exploration, Inc., written commun., 1977). His mapping outlined three units favorable for massive sulfide mineralization: the chlorite-carbonate schist, a quartz carbonate (sericitic phyllite), and a quartz graphite schist (differentiated from the graphitic schist unit intersected immediately below the ore horizon in DDH–1).

Noranda attempted to better define and describe the lithologic units, geological and structural setting, and mineralization style of the Big Sore deposit in the 1976 year-end report. The hanging wall was described as chlorite and sericitic tuffites representing volcaniclastics of a mafic to felsic cycle. The footwall rocks were described as epiclastic perigenic conglomerates and carbonaceous argillites (formerly the graphitic schist unit). The pyritic and high-sphalerite ore zones and carbonaceous cherts were classified as exhalative rocks. Essentially, Noranda was trying to pigeonhole Greens Creek into a Kuroko-type deposit. All of the lithologic units were interpreted as grading into one another. Noranda estimated that the mineralized zone contained ±0.5 million tons of ore (John Dunbier, Noranda Exploration, Inc., written commun., 1976).

An effort was made to determine the age of the described units. Despite the lack of any fossil control or unambiguous small-scale sedimentary structure (that is, graded bedding), Noranda correctly believed that the section was inverted (Noranda Exploration, Inc., written commun., 1977). The circumstantial evidence cited was the observed mafic to felsic volcanic cycle (incorrect), volcanic to sedimentary cycle, paleorelief features, and lithological and geochemical zonation within the exhalites similar to Kuroko-type deposits.

Structurally they observed that minor folds were very common, but no tight or isoclinal folds were found except within the carbonaceous argillites. The rare appearance of fault gouge, tectonic breccias, and slickensides did not allow for any major faults to be identified in the drill sections. However, evidence for intense deformation was described between the mineralized zone and footwall argillites, thought to be the result of adjustments induced by flexuring of units due to a major recumbent fold.

Noranda envisioned the Big Sore deposit as occurring in a predominantly sedimentary basin associated with a nearby mafic to felsic volcanic system. The quiescent submarine environment received ash but no intrusive or extrusive rocks from the volcanic system. The volcanic system did, however, give rise to hydrothermal systems and possible explosive exhalations (as evidenced by the conglomerates near the ore interface). Brines from the hydrothermal system settled into depressions and precipitated chemical sediments (sulfides, cherts, and carbonates). Noranda compared Greens Creek to "artesian" exhalative deposits similar to Iron King in Arizona, Faro in the Yukon, and Sullivan and Rosebury in Tasmania (Noranda Exploration, Inc., written commun., 1977). These geologic observations and deductions formed the working geologic framework for exploration work at Greens Creek and Northern Admiralty Island for the next 10 years.

1977 Program

The 1977 exploration program in the Greens Creek area included two projects; the Big Sore drilling program was the primary project, and detailed exploration of Mariposite Ridge, Gallagher, Killer, and Zinc Creeks was the other project. Noranda continued as the operator of both programs. Surface drilling included 22 holes totaling 8,810 feet, primarily along the Big Sore mineralization trend, but also in Gallagher and Killer Creeks. Soil grids were extended or established for all the prospects/areas mentioned herein. The second project was the most ambitious for the area surrounding the Big Sore prospect to date, and remained so until the passage of the Land Exchange Act spurred the exploration programs of 1996 to 1999.

Surface geologic mapping to the south and southwest outlined the carbonaceous argillite unit as wrapping around the tuffite units. The argillite unit was believed to be the upper limb of an overturned fold (John Dunbier, Noranda Exploration, Inc., written commun., 1977). A new soil grid of five lines oriented at N. 60° E.–S. 60° W. was emplaced over the upper limb contact zone. The soil anomalies generated were more erratic than those of the overturned limb, but local silver and zinc anomalous zones along the contact were delineated. A CEM geophysical survey delineated the argillite unit but did not generate any drill targets.

The 1977 drill program at Big Sore was a success in extending the known mineralized zone along strike and downdip. Eight diamond drill holes were drilled, totaling 4,446 feet, plus 1,415 feet of Hydra-Wink drilling. PS–4–77 (PS–23) intersected a 75-foot section that averaged 12.6 troy ounces per ton silver with a 3-foot high-grade section of 92.2 troy ounces per ton silver. This hole was located 900 feet to the southeast of PS–1. In addition, PS–5–77 (PS–28) intersected 6.5 feet of mineralized material about 300 feet downdip from PS–4–77. The mineralized zone was extended another 800 to 1,000 feet northwest of PS–6–76 by holes PS–6–77 (8.1 feet of 17 percent zinc and 12.25 troy ounces per ton silver) and PS–W1–77 (28 feet of 18.2 percent lead, 32.75 percent zinc, and 10.2 troy ounces per ton silver). PS–8–77 (PS–27) intersected 20 feet of ore 300 feet downdip from PS–3–76.

The total strike length of mineralized rock along the overturned limb now totaled 3,500 feet and was open on both ends (Noranda Exploration, Inc., written commun., 1977). However, future surface drilling did not extend the mineralized zone farther along strike in either direction. The mineralized interval also extended at least 500 feet downdip on many of the sections tested. The Noranda geologist (Dunbier) realized that the main mineralized zone was at the lithologic contact between the argillites and tuffites. The calculated, geologically indicated resource was 2.1 million tons with an NSR (net smelter return) value of about $90/ton (John Dunbier, Noranda Exploration, Inc., written commun., 1977).

Dunbier's recommendation for 1978 was to verify the geologically indicated resource with an underground drill program augmented with Hydra-Wink drilling from the surface. Drill hole PS–W1–77 showed that the Winkie drill was capable of piercing the overburden and the mineralized zone. The current 300-foot drill spacing was considered inadequate for ore reserve calculations, and it was recommended that the underground holes be drilled at regular spacings between the surface holes. Additional reserves could be added by downdip testing of the mineralized zone, drilling along strike to the south-southeast, and surface exploration of the upper limb contact (John Dunbier, Noranda Exploration, Inc., written commun., 1977).

Exploration continued within the Gallagher Creek prospect to follow up on the previous CEM and geochemical soil surveys and to test the massive sulfide outcrops and float. The Noranda geologists thought the rocks in Gallagher Creek were part of the upper (upright) limb of the Big Sore fold (Noranda Exploration, Inc., written commun., 1977). One Hydra-Wink hole was drilled on the west side of the creek and intersected weakly mineralized tuffites with one 5-foot zone of 10.2 percent zinc. The contrasting sections intersected by this hole and the two 1976 drill holes led them to believe that a fold or shear (later to be mapped as the Gallagher fault, a significant right-lateral fault) ran along Gallagher Creek.

Killer Creek was also extensively explored in 1977. The 1976 Gallagher–Killer Creek soil grid was extended, and a new grid with a baseline oriented southeast-northwest was surveyed in middle Killer Creek. The new Killer Creek grid generated 16 primary soil anomalies. Noranda identified three types of mineralization associated with the anomalies, which were tested by drilling. PS–77–1 (PS–20) tested below surface exposures of stringers, veins, and clots of coarse sphalerite with pyrite, magnetite, galena, and chalcopyrite within a talc-serpentine-chlorite-carbonate rock. No significant mineralized rock was intersected. A stratiform massive chalcopyrite, pyrite, and pyrrhotite band within greenstone in Upper Killer Creek was tested by two Hydra-Winkie holes, PS–W4 and PS–W5–77 (PS 32 and PS–33). Both holes intersected copper-bearing mineralized rock with grades up to 2.3 percent. Two other holes were attempted in lower Killer Creek to test stratiform sphalerite-galena sulfide bands, but the attempts failed to drill through the thick glacier till overburden.

Noranda recognized the Killer Creek sequence of rocks as distinct lithologies from Big Sore, consisting mostly of andesites, andesitic tuffs, and three types of serpentinites (one described as being a magnesium-rich exhalite)(Noranda Exploration, Inc., written commun., 1977). Noranda envisioned Killer Creek as a tectonic hinge zone, next to a subsiding sedimentary basin (Big Sore and Gallagher prospects), with active faulting, mafic volcanism, and associated exhalative activity. Noranda looked favorably upon the results and estimated that Killer Creek had the potential for 1–3 high-grade (greater than 10 percent zinc) deposits of more than 50,000 tons, at least one deposit of 2–5 percent zinc greater than one million tons, and one to three 1.5 percent copper deposits of greater than 100,000 tons.

Soil surveys, CEM and magnetic geophysical surveys, and geologic mapping were also carried out on the Zinc Creek and Mariposite Ridge prospects. The results from Zinc Creek were not encouraging: only weakly anomalous soil samples (as compared to Big Sore and Killer Creek grids) and no finite geophysical anomalies. On the other hand, the Mariposite grid generated nine soil anomalies associated with vein, disseminated stratiform, and massive stratiform lead-zinc mineralization within, or along the contacts of, the mariposite-carbonate unit. The Noranda geologists believed this unit was a metacarbonate (Noranda Exploration, Inc., written commun., 1977). Noranda suggested that the joint venture attempt to purchase the Mammoth claims not only for its mineral potential, but because its "main value would be as bargaining chips during land negotiations with federal bureaucrats" (Noranda Exploration, Inc., written commun., 1977).

The 1977 exploration program identified many targets and prospective areas outside the immediate Big Sore prospect and recommended continued work, including drilling at Gallagher and Killer Creeks and Mariposite Ridge. However, the urgency of proving-up the Big Sore deposit and events in Washington, D.C., worked against any further work until 1982.

Initial Underground Development and Land Battles, 1978–80

The Pan Sound Joint Venture was dissolved in 1978 and the Greens Creek Joint Venture formed in its place. The Pan Sound Joint Venture was redrafted in part due to the addition of Bristol Bay Native Corporation. The members of the Greens Creek Joint Venture decided in January of 1978 to begin underground diamond drilling and initiate an environmental baseline study after carefully analyzing the political, environmental, geological, and economic aspects of the project (Ernest Simmons, memorandum to W.W. Holmes, 1978). The Greens Creek Joint Venture agreed to a plan to drive a 4,200-foot drift from which to drill about 30,000 feet of core. The environmental baseline study began April 1 and was carried out by VTN Consulting.

The project's first legal battle came on May 2, 1978. The Southeast Alaska Conservation Council (SEACC), with the legal aid of the Sierra Club, appealed the Regional Forest Supervisor's decision to approve the exploration operation plan. They believed that public involvement was not adequately sought in the process. They cited the overwhelming opposition to the planned ferry dock on the north side of Douglas Island and the public's overall negative sentiment toward Noranda (Ernest Simmons, memorandum to W.W. Holmes, 1978). SEACC was also concerned with recent turbidity measurements in Greens Creek that violated USDA Forest Service regulations. Their appeal was denied by the Regional Forest Supervisor on grounds that public involvement is not necessary for an exploration plan and that Noranda was taking the proper steps to mitigate the turbidity exceedances caused by heavy rains.

Driving of 1350 Drift

Noranda contracted the Mining Company of Denver, Colorado, to drive an exploration drift (1350 Drift) at the 1,350-foot elevation mark. Glacial overburden was removed from the portal site by July 13, 1978, and the initial bench round was drilled out on July 14 (Ernest Simmons, memorandum to W.W. Holmes, 1978). By the end of the year, 1,667 feet of drift had been driven, including drill station cutouts at 150-foot spacings. Work continued through the winter and spring months (with a 45-day weather shutdown in February and March) in an effort to complete the 1350 Drift (T.A. Butler, memorandum to S. Nakata, 1979). The drift was finished in November 1979. A total of 4,190 feet of drifting with a 219-foot rise was completed along with 24 diamond drill stations, assorted sumps, and an underground shop. All work was completed using helicopter support and a camp located just below the portal. The total cost for the 1978–79 drifting and drill program was $5.05 million (Noranda Exploration, Inc., written commun., 1980).

The initial underground drilling program began in October 1978 and finished in December 1979. Drilling took place on an intermittent basis as new drill stations were cut, and water and power became available from the drifting program. Fifty holes (GC–1 to GC–50) were drilled during this period, totaling 20,240 feet (Noranda Exploration, Inc., written commun., 1980). Most of the drill stations (14 out of 24) were drilled out to help confirm the 2,750 feet of strike length of mineralized rock. The fifty drill holes encountered 59 ore intercepts. Noranda estimated the drill indicated reserves to be about 3 million tons with an approximate grade of 10–16 troy ounces per ton silver, 0.1 troy ounce per ton gold, 7–10 percent zinc, 2–2.5 percent lead, and 0.5 percent copper. The ore zone was still believed to be open downdip and along strike to the southeast (Noranda Exploration, Inc., written commun., 1980).

Noranda performed a base cash-flow model for Greens Creek to estimate the economics of the project. The order of magnitude estimates indicated that the project had a DCF–ROR (discounted cash flow – rate of return) of 39.3 percent, NPV (net profit value) of $22.6 million, with payback in 1.8 years (Noranda Exploration, Inc., written commun., 1980). Assumptions and criteria used for the estimate included metal prices at $300 per troy ounce gold and $10 per troy ounce silver, a production rate of 800 tons per day (TPD), $18.4 million in preproduction costs, $65 per ton operating costs, and 15.75-year mine life. However, Noranda concluded that "Political imponderables far exceed the technical unknowns insofar as the Greens Creek project is concerned" (Noranda Exploration, Inc., written commun., 1980).

The land status of the Greens Creek property changed greatly during the underground drifting and drilling program. Nineteen Big Sore claims were surveyed for patent in July and submitted to the Cadastral Survey Office in April 1979 (T.A. Butler, memorandum to S. Nakata, 1979). The Greens Creek Joint Venture employed the law firm of Pruitt and Gushee of Salt Lake City to aid in the intricate patenting process. An additional 27 lode claims were staked during 1978: 23 to the south of the Big Sore group to cover the downdip projection of the current orebody, three on the southwest to cover an area dubbed the "football field" that was a potential tailings site, and one to cover an open area that developed as a result of the patent survey. A total of 136 mill-site claims were staked to the south and east of the Hawk Inlet Cannery site between November 27 and December 1. The latter date, December 1, proved to be a very fateful day that would change the whole scope of the project and have repercussions throughout the entire State of Alaska.

Federal Proclamations

Federal land-management policy in Alaska was one of the hotly debated topics during the 95th Session of the United States Congress. The Alaska Native Claims Settlement Act (ANCSA) of 1971 provided an 8-year time limit for Federal action on protecting or otherwise designating use of "special national interest lands" that up to 1978 were termed "d-2" lands. The largest conservation lobby ever assembled along with politicians like Congressman Morris Udall and Secretary of the Interior Cecil Andrus were concerned with the fast-approaching 8-year deadline of December 18, 1978 (Nash, 1982). They were worried that if no protective action were taken, there would be a huge "land grab" by mining companies and other developers within pristine parts of Alaska. They felt once the deadline was passed, State, Native, and private parties would be able to stake claims on Federal land, which constituted 99 percent of Alaska. If this happened, they reasoned it would be hopelessly complicated to establish any new national parks or wilderness areas. Bill HR–39, which would have protected 92 million acres of Federal land in Alaska, passed through the House of Representatives by a wide margin. However, Alaska Senator Mike Gravel's threatened filibuster of any bill that withdrew or placed restrictions on Federal land in Alaska stalled the bill in the Senate (Nash, 1982).

The Carter administration took action once it was evident that Congress was not going to pass any Alaska land bill by the end of the congressional session. Interior Secretary Andrus withdrew 110 million acres of Federal lands in Alaska from all forms of development for 3 years on November 16. He used the 1976 Federal Land Policy and Management Act to authorize this action. This act was controversial, and many thought it to be unfair since it was made before the close of the comment period (November 20) on the draft Environmental Supplement (T.E. Butler, written commun., 1978). The Environmental Supplement was to document, in part, the impact on Alaska citizens of the closing to development of land in Alaska. The lands withdrawn included most of Admiralty Island, including Greens Creek.

The big move came on December 1, 1978, when President Jimmy Carter declared 56 million acres of Federal land, including most of Admiralty Island, as national monuments under the authority of the 1906 Antiquities Act, which was designed to protect places of historical interest. Never before had the act been used on such a colossal scale (Nash, 1982). This move was applauded by the numerous conservation and environmental organizations and by the American public in general. Most Alaskans reacted with shock and outrage. The national monument status still had to be approved by Congress, giving the Greens Creek Joint Venture time to formulate a strategy to lobby Congress.

Immediately the land position of the Greens Creek Joint Venture was in jeopardy. The Greens Creek Joint Venture felt that their prior existing rights to the claims would be honored (T.E. Butler, memorandum to S. Nakata, 1979). However, there was a question as to whether a mine could be established within a designated monument, since there was no legal precedent. The 1979 Minerals Availability System Deposit Summary Report by the Bureau of Mines listed the land environmental factor as “prohibitive” until the status is legislatively determined in court (T.E. Butler, memorandum to S. Nakata, 1979). Claims could no longer be staked, nor could any surface construction activities not already approved under the 1978 Exploration Work Plan take place until the USDA Forest Service validated those claims. Considerable energy and resources were expended during the next 2 years to gain legislative relief from the Carter administration decision.

The next 2 years saw extensive lobbying by both sides. Noranda and the Joint Venture partners were actively lobbying Congress for a less restrictive designation for the Greens Creek drainage. One such group that the JV helped fund was the Citizens for Management of Alaska Lands (T.E. Butler, memorandum to S. Nakata, 1979). On the other side of the fence was the Alaska Coalition made up of the Nation’s five leading conservation groups (Sierra Club, Wilderness Society, the National Audubon Society, Friends of the Earth, and the National Parks and Conservation Association), the largest and most powerful conservation group ever assembled in American history (Nash, 1982). The House passed Bill HR–39 in May of 1980, which would have recognized the Greens Creek deposit but would have surrounded it with land designated as wilderness. The Senate passed a much less restrictive bill (S–9) sponsored by Alaska Senator Ted Stevens that excluded Greens Creek from the national monument. House leaders initially did not wish to compromise on their bill, but on November 4 Ronald Reagan was elected president and they realized they had only a small window of opportunity left to pass a bill that would not be vetoed (Nash, 1982). The compromised bill was named the Alaska National Interest Land Conservation Act (ANILCA).

President Carter signed ANILCA into law on December 2, 1980. The act set aside 104 million acres of Federal land in Alaska for permanent protection. The Greens Creek deposit was included in the newly created Admiralty Island National Monument but was excluded from wilderness classification. It was decided legislatively that the Greens Creek project should proceed. Section 504 of ANILCA allowed for exploration on previously located, unpatented claims that fell within three-quarters of a mile of a valid mineral discovery. However, exploration would have to cease in 5 years and any claims not “perfected” would revert to national monument status. Thus the Joint Venture had until December 2, 1985, to perfect any of the 127 claims that fell within the 0.75-mile radius.

1980 Exploration Program

Exploration work was limited while the above political and legislative battles took place. Restrictions were placed on surface activities, and the previously approved plan of operation was only valid until May 31, 1980. Resources were directed toward finishing the environmental impact statement (EIS), which was taken over by International Environmental Consultants. Thirty-three drill holes (GC–51 to GC–83) were completed by the end of March (Noranda Mining, Inc., written commun., 1981). Another 35 feet of drifting intersected the footwall argillite at the south end of the 1350 exploration drift. An important milestone in 1980 was the USDA Forest Service Mineral Examiner’s report that recognized valid discoveries on seven Big Sore claims (Noranda Exploration, Inc., and Noranda Mining, Inc., written commun., 1981). These seven claims formed the core claims with surface and subsurface rights.

Race to “Perfect” Claims and Predevelopment, 1981–85

1981 Exploration Program

With the political situation clarified by the passage of ANILCA, the Greens Creek Joint Venture members approved the appointment of Noranda Mining, Inc., as the operator, replacing Noranda Exploration. This change emphasized the point that Greens Creek was passing from the exploration stage to development. Much of the activity in 1981 reflected this change in status. The primary emphasis was on environmental and engineering studies of various components of the project. The various projects completed included road alignment surveys from Young Bay to the Hawk Inlet Cannery, drilling and geophysical investigations of the tailings site near the cannery, and boat transportation study. The draft EIS was completed by December (Noranda Exploration, Inc., and Noranda Mining, Inc., written commun., 1981).

No surface exploration work was documented for the 1981 summer season. Despite the fact that the clock was already ticking on the 5-year exploration limit, Noranda chose to work on development issues. The USDA Forest Service approved the exploration permit in April; thus, the permit was not the limiting factor for exploration. Noranda lost one valuable season for perfecting claims as they pursued other studies of the project.

Underground development continued in 1981. A 424-foot crosscut was driven from the 1350 adit to expose the ore zone. The drifting continued along the ore to the north and south for a distance of 176 feet (Noranda Mining, Inc., written commun., 1981). This provided material for a 4,200-pound bulk sample for metallurgical bench flotation tests in Salt Lake City. The first exposure of the ore zone in three dimensions provided a “quantum leap” in the knowledge of the deposit (Noranda Mining, Inc., written commun., 1981). The exposure helped to confirm that three types of ore (Massive, White, and Black) were present and relatively lithologically discrete from each other. Vein mineralization, especially with regard to precious metal upgrading, was found to be more prevalent than thought from data obtained from the diamond drill core. Coarse visible gold was intersected in several areas. Overall, the Noranda geologists believed that the original reserve and grade estimates were too conservative based on the precious metals intersected and the inability of the LHDs (load, haul, dump equipment) to carry a full bucket of ore (Noranda Exploration, Inc., and Noranda Mining, Inc., written commun., 1981). A tonnage factor of 9 cubic feet per ton was more realistic than the original estimate of 11 cubic feet per ton. The crosscut also exposed ubiquitous intermediate scale folds (25–75-foot wavelengths) oriented normal to the interpolated large-scale folds that would have great implications for mining methods and grade, tonnage, and dilution estimates.

More legal difficulties arose in 1981. The Southeast Alaska Conservation Council (SEACC) and the Sierra Club challenged the USDA Forest Service’s granting of the exploration permit for a second time. They appealed the granting of the exploration permit to the Chief Forester on the basis that the original claims were not valid as of December 1, 1978 (Noranda Exploration, Inc., and Noranda Mining, Inc., written commun., 1981). They argued that the Greens Creek deposit did not pass the marketability test, and no reclamation costs were included in the study. The Regional and Chief Foresters sustained the previous decisions, stating that the mineral inspector used the correct criteria for determining that the seven core claims contained valid mineral discoveries.

1982 Drill Program

Noranda shifted emphasis back to surface exploration and drilling in 1982. The goal was to validate unperfected claims and add to the total mineral inventory. Noranda Exploration, Inc., led by Joe Drechsler, was contracted by Noranda Mining, Inc., to manage the program (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982). Noranda drilled 12 holes totaling 11,210 feet during the summer field season. Nine of those holes were in the Big Sore area, two in Gallagher Creek, and one in Bruin Creek, on the north side of Greens Creek.

The Big Sore drilling program successfully intersected discoveries on unperfected claims. Three holes were drilled to test the northwest strike extension of the orebody on claims 1107 and 1108. All three intersected only minor mineralization, and the lack of chert buildup (siliceous alteration) along the argillite/phyllite contact suggested that the ore pinches out to the north (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982). On the south side of the orebody, only argillite was contacted in hole GC–82–9 (PS–50) targeting claim block 901. Holes GC–82–2 (PS–43) and GC–82–7 (PS–48) tested the downdip extent of the argillite/phyllite contact. Both holes intersected thin (4-foot) ore intercepts with high-grade silver up to 26.7 troy ounces per ton. The ore intercepts in these two holes were at a higher level (about 500 feet) than expected from projections from previous holes, indicating flattening of the ore horizon due to folding or faulting. Holes GC–82–8 and GC–82–10 (PS–49 and PS–51) were drilled from claim 1106. GC–82–8 intersected 12 feet of 26.7 troy ounces per ton silver and 11.93 percent zinc. The other hole intersected a barren contact. The final hole of the season, GC–82–12 drilled from claim 1107, intersected a 6-foot interval of argillite running 6.22 troy ounces per ton silver, 3.75 percent lead, and 4.10 percent zinc. Noranda did not make clear in the yearly report which of these intersections would qualify for discovery and claim validation.

The two holes in Gallagher Creek attempted to better outline the mineralization present there from intercepts from the 1976–77 drilling program and test for Greens Creek-type stratigraphy. Drill hole GC–82–5 (PS–46) was successful in intersecting 15 feet of high-grade zinc mineralization (10.22 percent). The hole was located on claim 1304 at the western edge of the 0.75-mile limit. The other hole, GC–82–11 (PS–52) located farther south, intersected minor zinc enrichment. The Bruin Creek hole GC–82–6 (PS–47) was drilled on claim 1213 and intersected several 3–5 foot sections of chert-carbonate rock containing up to 1 percent zinc. However, Noranda did not view the results as being favorable for discovering any significant sulfide occurrences in the area (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982).

Noranda still saw Greens Creek as being open along strike to the northwest and downdip, with the potential of another 2–5 million tons of ore (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982). Noranda felt that five of the holes drilled on unperfected claims intersected mineralization of sufficient quality and quantity to be considered "discoveries." However, section 504(e)(1) of ANILCA left some doubt as to what constituted a valid discovery; whether the standards applied would be those of the USDA Forest Service Mineral Examiners or the stricter Bureau of Land Management (BLM) requirements for issuance of a patent (which appeared to be how the section was worded) was unclear. An unofficial draft of the Mineral Examiner's report stated that claims 1304 and 1305 in Gallagher Creek contained valid mineral discoveries, but claim 1605 in Killer Creek did not. Noranda maintained that drillcore of 2.3 percent copper is a valid discovery, but their legal counsel suggested that this interpretation would not hold up in court (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982).

Noranda and the JV partners reviewed other options and strategies to protect the exploration potential of Greens Creek. The alternatives to the current aggressive discovery-oriented drill program included a minor boundary change putting Greens Creek outside the national monument, a land swap, or extension of the 5-year period to prove the claims (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982). The first choice was to lobby the USDA Forest Service for a minor boundary adjustment, a power the USDA Forest Service had under one of the provisions of ANILCA. The other two choices were less attractive because a land swap would be costly and an extension would only delay resolution of the problem.

The cost of the drill program was becoming a concern for Noranda. More definition drilling was necessary to bring the "new" 1982 geologically inferred reserves into indicated reserves (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982). Even at 400-foot spacings, it would require about 11,000 feet of surface drilling to validate indicated reserve status, leaving very little funds for perfecting claims. Drilling on 150-foot centers, which was preferred, would be extremely expensive. Underground drilling would be less expensive, but the platforms did not exist and would be best established simultaneously with mine development and mining, still years away. Underground and surface drilling both would require helicopter support, adding to the cost. Drilling would be much less expensive after road construction, but road construction might not be possible until after the expiration of the permit period due to political and budget constraints. Noranda was faced with either continuing drilling at a higher expense or pursuing the above-land options and risk losing potential mineral assets.

Noranda Exploration geologist Daryl Scherkenbach completed a geologic mapping project at a scale of 1 inch=500 feet for the Greens Creek area. This work was the basis for his geologic model of the Greens Creek deposit. He suggests that the Big Sore orebody formed within a second- or third-order extensional basin (D.A. Scherkenbach, written commun., 1983). In his model, tectonic extension was accompanied by mafic and ultramafic volcanics and shallow intrusives. The serpentinization of these rocks is a strong indicator of hydrothermal activity that caused the metal transportation. The effusive vents for the hydrothermal fluids manifested themselves as slump breccias, as mapped within the footwall tuffites. These vents formed fault scarp basins, in which the metallifereous brines could settle and deposit metals. The massive ores accumulated near the vents while black ores accumulated distally, hundreds of meters from the vent. The white ores represented remobilized sulfides as the solutions migrated around sulfide-clogged vent areas. Scherkenbach thought the difference between the sericitic and chloritic tuffites/sediments was due to different source areas or modes of deposition. The highly negative δS isotope values for the argillite and black ore indicate biogenic reduction of seawater sulfate. The less negative values for the remaining ore types and tuffites suggest a mixing with magmatic sulfur.

1983 Feasibility Study

Noranda completed a feasibility study in 1983 that outlined the economic viability of the project. The study was based on probable and possible reserves (including dilution due to mining method) of 2.84 million tons at 0.093 troy ounce per ton gold, 14.42 troy ounces per ton silver, 2.93 percent lead, and 8.56 percent zinc located above the 950-foot level. An additional geologic reserve of 1.45 million tons was estimated to be below that level (Noranda Mining, Inc., written commun., 1983). Noranda envisioned using conventional cut and fill mining methods utilizing jacklegs within "captured" stopes. Five to six separate levels/portals on 200-foot spacings would be connected by a winze and raises. Rail haulage would take place on all levels. Noranda preferred this method to mechanized cut and fill to reduce the amount of ramp development and allow for more selective mining where the ore is too narrow for rubber tire equipment. Mining rates were estimated at 1,200 tons per day (TPD) with dilution at 17 percent and mining recovery at 90 percent. Carbon, lead, and zinc concentrates would be produced over the estimated 20-year mine life (including development time). The mine would have a workforce of 344 people. The economic/cash-flow model given these parameters required a 1987 silver price of $22.95 for a 15 percent DCF–ROR. The estimated capital investment was $254.3 million with an operating cost of $151.85 per ton (Noranda Mining, Inc., written commun., 1983). This was a huge contrast from the 1980 estimate of 39.3 percent DCF–ROR and $65 per ton operating costs.

1983 Exploration Program

The objectives of the 1983 program were much the same as before, to validate peripheral claims and continue detailed definition drilling of the southern end of the orebody. The management of the program fell back to Noranda Mining, Inc., with Edwin Harrison supervising. The decision to proceed with the drill program did not come until July 7, and the four crews required for the work were not completely mobilized until August 1 (E.D. Harrison, Noranda Mining, Inc., written commun., 1983).

A total of 17 holes were drilled during the season. Most of the holes (15) were drilled from the southern core claims (902, 903, and 904). The aim was to upgrade the southernmost part of the resource to measured reserves status. Noranda viewed the south end as being critical to the initial mine design and development, and they needed a better understanding of the fold closure (E.D. Harrison, Noranda Mining, Inc., written commun., 1983). Three holes drilled updip from the 1982 ore crosscut intersected white, massive, and black ore of economic length and grade. One hole drilled at the southernmost known limits of the orebody intersected 12 feet of high-grade precious metals (0.644 troy ounce per ton gold and 55 troy ounces per ton silver). This hole also tested the upper limb argillite but intersected no mineralization. The remaining nine holes were in-fill drillholes of which five intersected significant ore intervals. The in-fill holes helped "prove" the continuity of ore in the south end of the designed mine plan and helped define the major fold closure controlling the ore to the south (E.D. Harrison, Noranda Mining, Inc., written commun., 1983).

Many high-grade intercepts were assayed during the drill program. A 2-foot interval from PS–62 assayed greater than 11 troy ounces per ton gold, which was confirmed by numerous re-assays. Noranda considered the question of cutting high gold/silver assays for reserve calculations. They felt this idea should be studied closely and put into practice (E.D. Harrison, Noranda Mining, Inc., written commun., 1983).

Little effort was made in proving unperfected claims in 1983. Only two holes were drilled and an older hole was reentered and wedged in a different direction. PS–70 was drilled on claim 1107. Perfecting this claim was a high priority because the 1350 portal, mine camp, and waste dump were all located there. The hole intersected a short (1-foot) but high-grade (109 troy ounces per ton silver) mineralized zone deemed sufficient to prove the claim. The attempt to prove claim 1003 was an expensive ordeal (E.D. Harrison, Noranda Mining, Inc., written commun., 1983). The target was a recumbent drag fold intersected just outside of the claim by PS–48 (1982). An attempt was made to reenter that hole and place a directional wedge to deflect the hole onto claim 1003. The wedge failed to deflect the hole. A new hole, PS–54, was collared at the same site. Despite orienting the hole to compensate for the expected deviation, downhole surveys showed the hole was going to miss the projected contact to the northeast. Poor weather forced the postponement of the drill program before another mechanical wedge could be used to correct the hole. Thus, a valid discovery was made on only one unperfected claim in 1983, with only 2 years remaining on the exploration permit.

The first change within the Greens Creek Joint Venture partners occurred in 1983. Anaconda purchased all of Martin-Marietta's interest in the Greens Creek Joint Venture in March of 1983 after first approaching them in December of 1982 (Anaconda Minerals Company, written commun., 1984). Anaconda already had exploration experience in southeast Alaska, including the Pyrola claims to the south of Greens Creek. Anaconda's Project Evaluation Report in January of 1984 justified their purchase on the basis of Noranda's prefeasibility study. They believed that Noranda's approach was too conservative and estimated the minable reserve greater by 0.5 million tons with higher silver (16 rather than 14.4 troy ounces per ton) and gold (0.11 rather than 0.093 troy ounce per ton) grades. In addition, they thought that utilizing the mechanized cut and fill mining method would reduce capital costs for full production by 20 percent from Noranda's conventional cut and fill proposal.

Anaconda saw many potential problems with the project. They were concerned with the marketability of the concentrates produced due to the high level of contaminants (cadmium, arsenic, antimony, and mercury). Other concerns were the limited size and accessibility of Juneau, making it difficult to obtain and keep experienced personnel. They felt the lower levels of the deposit lacked the necessary drilling for production to be justified. Anaconda foresaw future delays in the project due to political and environmental factors. However, they did not see the pending exploration deadline and land issues as having an adverse effect on the base case economics. Anaconda's preferred solution to the land situation was a land exchange with the Federal Government (Anaconda Minerals Company, written commun., 1984).

1984 Exploration Program

The 1984 drill program budget was $3.3 million, a fivefold increase from the $0.655 million budget of the previous year (E.D. Harrison and others, Noranda Mining, Inc., written commun., 1984). The increased budget, and the primary objective of the 1984 drill program to extend the proven claim block to the north and south, underscored the increasing pressure of the exploration deadline. The northern claims were tested to the 0.75-mile limit by surface holes while the southern claims could only be tested practically by underground drilling. Surface holes would be too long as a result of the increase in topography and southeast-plunging ore zone. An 847-foot-long drift (1984 crosscut) was driven to the edge of the unperfected claims, with drill-cuts along the way for detailed ore reserve drilling.

The secondary objective of the 1984 program was to increase the downdip potential of the previously defined ore zones. The deposit was now divided into three ore zones, the North, South, and Central zones. The drilling took place from the 1350 drift and the new 1984 crosscut. Much rehabilitation work had to be completed on the 1350 drift due to numerous ground falls since 1981 before drilling took place.

The farthest north and northwest drilling in Gallagher Creek (PS–83), Killer Creek (PS–82, PS–86), and Bruin Creek (PS–76 to PS–81 and PS–84) failed to intersect mineralization sufficient to perfect claims. Likewise, hole PS–75 located near the camp on claim 1108 did not intersect mineralization along the argillite/phyllite contact. Drillholes closer to the core claims were more successful. PS–72 and PS–73 extended the now-named North Ore zone downdip another 250 and 350 feet, respectively, although the intersections occurred on already perfected claims. PS–74 intersected the North Ore zone at the 400-foot level with a 7-foot interval of 17 troy ounces per ton silver and 5 percent zinc. This was the deepest ore intersection to date and perfected claim 1105. Another hole, PS–85, tested claim 1106 and intersected the North Ore zone and 9.4 feet of "black" ore mineralization. This hole perfected claim 1106.

Most of the barren surface holes intersected chloritic sediments or mudstones instead of cherty sericitic tuffites above the argillite contact. Noranda believed that the chloritic rocks were not very conducive to Greens Creek-type ore mineralization, though they did not state any geologic reasoning for their conclusion (E.D. Harrison and others, Noranda Mining, Inc., written commun., 1984).

No claims were perfected on the south end of the ore trend. Three holes were attempted from the southern end of the 1984 crosscut, and all three terminated within 220 feet of the collar due to poor drilling conditions caused by a major northwest-trending fault (later defined as the Maki fault). Another attempt was made to perfect claim 901 to the south by drilling from a station farther back in the crosscut. However that hole, GC–91, intersected a barren contact within that claim. The in-fill drilling was very successful in increasing the reserves. Two stations were drilled from the new 1984 crosscut to test the downdip potential of the South Ore zone while one station was drilled from the 1350 exploration drift to test the downdip potential of the Central Ore zone. Hole GC–86 intersected numerous fold-repeated ore intervals, the lowest of which was located within the southeast corner of unperfected claim 1003. Noranda thought that the 5.9 feet of 16 troy ounces per ton silver would be sufficient to perfect this claim (E.D. Harrison and others, Noranda Mining, Inc., written commun., 1984). Two holes drilled in the South Ore zone, GC–88 and GC–94, intersected ore of higher precious metal grade, coarser grain size, and silica-baritic groundmass that had not been identified previously. Noranda thought that they might be approaching the primary vent to the south and that the grades might continue to increase downdip and to the south (E.D. Harrison and others, Noranda Mining, Inc., written commun., 1984).

The underground drilling program was successful in delineating more reserves below the 950-foot level and provided more insight to fold and fault structures, especially in the southern part of the deposit. Noranda did not add these new reserves to the "probable" category because they were not drilled on 150-foot centers (E.D. Harrison and others, Noranda Mining, Inc., written commun., 1984). However, they believed that the number of good ore intercepts supported the assignment of these areas into the geologic resource category. Thus, they classified the preliminary estimate of 670,000 tons to the "possible" category, with the majority of the tons in the North and South Ore zones. The increase in possible reserves, especially for the North Ore zone, was expected to have a large effect on the mine plan.

Other work included mining of ore underground for two bulk samples, one to be tested by Noranda and the other by Anaconda. Noranda geologist Floyd Branson initiated a trenching program in an attempt to expose the productive contact and patent claims 1007 and 1107. "Discovering" mineralization on the surface would allow the Greens Creek Joint Venture to exert extralateral rights under the Apex Rule (E.D. Harrison and others, Noranda Mining, Inc., written commun., 1984). The work was very difficult and expensive due to the difficulty in locating the contact under the thick glacier overburden.

Tom Crafford of Anaconda began his active role in the project by completing an extensive geologic mapping project to the north and east of the Greens Creek core claims. Crafford's surface mapping included defining two northwest-trending faults, one on Mariposite Ridge just west of the Mammoth claims, and the other at the head of Big Sore Creek. He believed that these faults were the same structure (T.C. Crafford, written commun., 1984). Sampling of mineralization on the Mammoth claims showed ore-grade material within mariposite-carbonate rocks, which Crafford thought might represent a link between that alteration style and the mineralizing event. Several rock samples were taken for conodont analysis for age determinations, as there was a debate whether the age of the Greens Creek orebody was Paleozoic or Triassic. However, these samples were barren. He also mapped to the northeast of the mine to determine whether or not the overturned limb of the Big Sore anticline reappeared on the surface, but he found no evidence of a fold repeat.

Some of Crafford's ideas expressed in his report were contrary to Noranda's view of the geology. He did not agree with the tuffite designation for the footwall rocks. He viewed these rocks as hydrothermally altered mafic rocks that were proximal to vents (T.C. Crafford, written commun., 1984). He was also doubtful of the large-scale anticline hypothesis.

The end of the year saw a change in the ownership of the Greens Creek Joint Venture. Anaconda and Noranda equally bought out Bristol Bay Native Corporation's properties at Hawk Inlet for a cash payment and a 0.28-percent net smelter royalty. The land would revert back to Bristol Bay upon termination of the Greens Creek Joint Venture.

1985 Surface Exploration Program

The objectives remained much the same as previous years for the 1985 drill program, the final year of the exploration permit granted under ANILCA. The surface drilling of 10 holes totaling 12,266 feet was designed to perfect as many claims as possible. The underground drill program involved definition drilling on 150-foot centers to place 1984's "possible" tons into the probable reserve category. This was the largest underground drill program to date, totaling 47 holes and 34,749 feet of drilling.

PS–87 was the only surface hole successful in perfecting a claim. The hole was drilled vertically from the northwest corner of claim 1206 to test the area between Gallagher Creek to the west and the North Ore zone to the east. The hole intersected 11.3 feet of "black ore" averaging 0.114 troy ounce per ton gold, 16.88 troy ounces per ton silver, and 4.9 percent zinc (E.D. Harrison and M. Severson, Noranda Mining, Inc., written commun., 1985). The intercept was 40 feet inside claim 1207 due to hole deviation. A wedged hole off of PS–87 also intersected 5.6 feet of ore-grade material, but it too missed claim 1206. Ed Harrison recognized this intersection as a separate orebody that to this day is still isolated from the nearest defined orebody by about 1,000 feet. PS–88 through PS–92 were drilled from already perfected claims 1106 and 1107 to define the eastern edge (or upper shelf) of the North Ore zone. PS–92 was the first and only hole drilled on the east side of Big Sore Creek, above the High Sore, another ferricrete kill zone (fig. 1). Highly fractured and deformed argillite was the only lithology encountered in PS–92. The remaining four holes were drilled on claims 1207, 1208, and 1209 to follow up the ore intercept in PS–87. None of these holes intersected significant mineralization.

The underground drill program was successful in delineating more reserves in all three ore zones. Noranda nearly doubled the probable reserves, adding another 1.33 million tons to the already identified 1.333 million tons (fig. 3). The total tonnage of 2.663 million at 0.13 troy ounce per ton gold, 22.24 troy ounces per ton silver, 3.49 percent lead, and 9.00 percent zinc exceeded their original goal of 2.1 million tons (Noranda Mining, Inc., written commun., 1985). Noranda was very optimistic due to the fact that the grades were increasing with depth and all three ore zones were still open at depth. Hole GC–139, drilled from the southern end of the 1984 crosscut, succeeded in perfecting claim 1002 with numerous 8- to 13-foot ore-grade intercepts. Four holes were attempted from the same station to perfect claims 901 and 1001 to the south. They were all abandoned or lost, however, due to poor drilling conditions in the fault zone where three drill holes were lost in 1984.

The Greens Creek Joint Venture's land position was augmented in 1985 with the signing of an exploration/development agreement with the owners of the Mammoth claims. The agreement was a 10-year lease with a drill commitment and royalty payment due to the owners on any production (E.D. Harrison and M. Severson, Noranda Mining, Inc., written commun., 1985). The old "Mammoth Tunnel #2" was cleared and mapped. Other old pits and trenches were sampled. A grab sample of a tetrahedrite-bearing outcrop just above the portal assayed at 0.778 troy ounce per ton gold, and 17.91 troy ounces per ton silver. An additional 85 claims were staked to the north of the Mammoth claims, just outside the monument boundary, to cover ground not claimed by the Lil Sore claim group controlled by the Norbritex Venture. The crew spent more than 3 weeks staking claims, enduring snow depths up to 12 feet (E.D. Harrison and M. Severson, Noranda Mining, Inc., written commun., 1985).

The south face of the 1981 ore crosscut was advanced to test the ability of the miners and grade-control geologists to stay on the ore and to test the lateral variability of the ore types. This experience left Noranda feeling that it would be a face-to-face requirement of the production geologist to follow the highly deformed ore (E.D. Harrison and M. Severson, Noranda Mining, Inc., written commun., 1985). A United Nuclear's silver probe was successfully tested as a grade control tool in estimating silver content of drill-core and face chip samples.

Land Strategies and Negotiations, 1983–85

While the exploration projects tried to perfect as many claims as possible before the December 2, 1985, deadline, efforts were underway to find a legal solution or compromise to the dilemma. Just prior to the deadline, the Greens Creek Joint Venture filed proof of discovery of nine additional claims (1002, 1003, 1004, 1005, 1105, 1106, 1107, 1207, and 1304) to add to the original eight core claims (E.D. Harrison and M. Severson, Noranda Mining, Inc., written commun., 1985). The Greens Creek Joint Venture was concerned that the accelerated exploration was too costly and risky, and other avenues needed to be explored to remedy the land situation. The three separate avenues that were explored are discussed in the following paragraphs.

The first option was a boundary change regarding the Admiralty Island National Monument (AINM) and wilderness areas. ANILCA (section 103b) allowed for the Forest Service to make minor boundary adjustments to the various land selections. This idea was being pursued as early as 1983. The Greens Creek Joint Venture was hoping to exchange 18,174 acres of private land in the Young Bay/Young Lakes area for 17,225 acres within the Greens Creek area. However, the Sierra Club was against the boundary change even if it meant no net loss to the AINM because it would set a precedent for boundaries based on economics. Attorneys for Noranda thought any changes in boundaries were unlikely because the USDA Forest Service would be named as the defendant in any litigation, threatening their power to grant minor boundary changes (J.P. Tangen, esq., memorandum to P. Richardson, 1983). In addition, Noranda would not be involved directly in the litigation, thus losing control of the nature and timing of any solution.

The second option that was pursued was legislative relief through extension of the exploration permit (J.P. Tangen, esq., memorandum to P. Richardson, 1983). Representative Don Young, Alaska's sole representative, introduced bill H.R. 2651 on June 3, 1985, to amend section 504 of ANILCA. The amendment would allow the Greens Creek Joint Venture to renew the 5-year exploration permit up to six times so exploration could continue until December 2, 2020. Senator Murkowski of Alaska introduced an identical bill as S. 1330. These bills would only provide for exploration within the 0.75-mile limit. However, neither bill made it out of committee.

The third option was a proposed land exchange involving Sealaska, the southeast Alaska Native corporation. The first iteration of the land-exchange proposal called for Sealaska to exchange subsurface mineral rights in the Cube Cove area for subsurface rights in the Greens Creek area. This land was

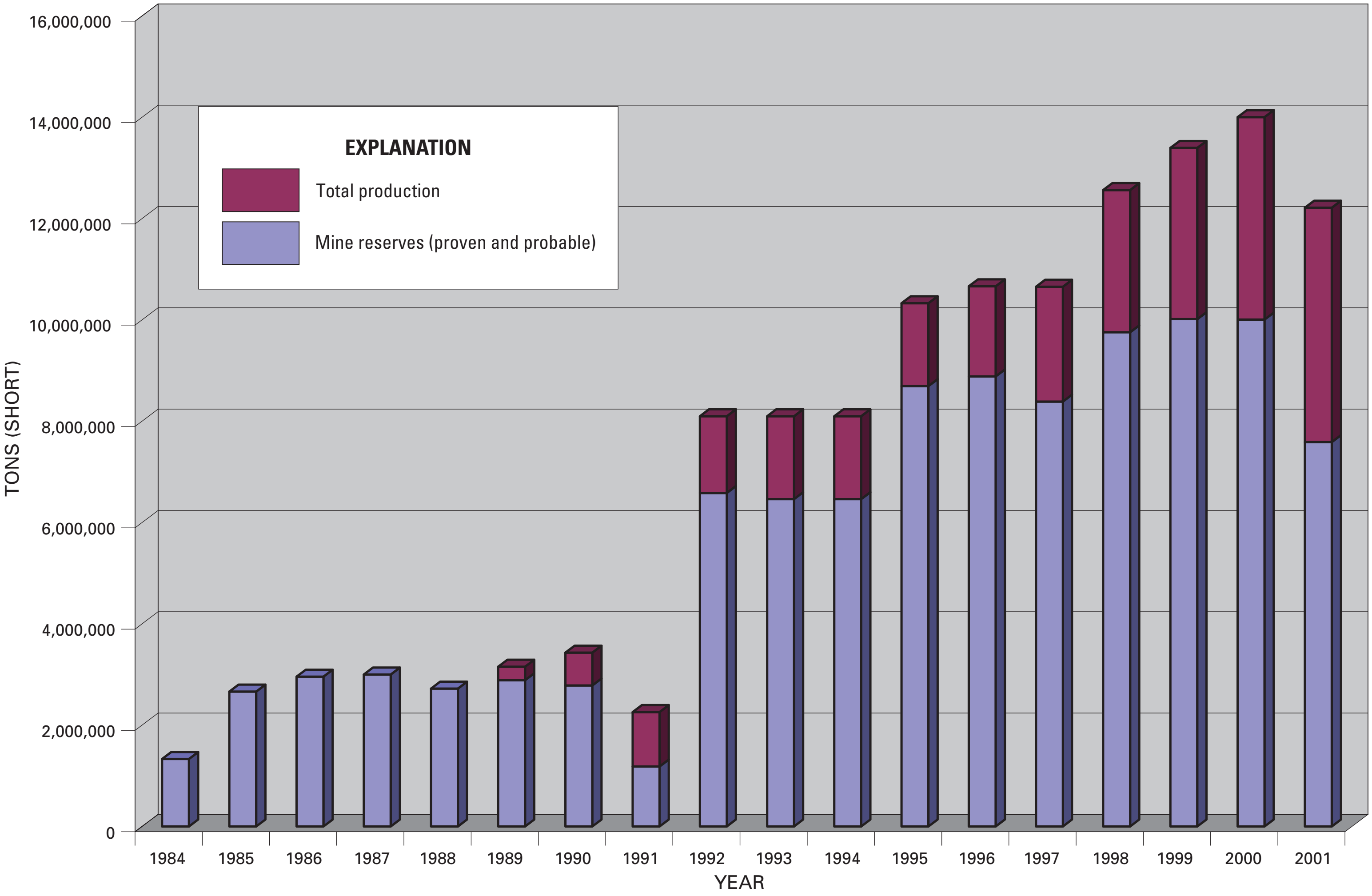

Figure 3. Chart showing proven and probable reserves compared to total (cumulative) production (Kennecott Greens Creek Mining Company, written commun., 2001).

selected by Sealaska under ANCSA. The tentative agreement reached in November of 1985 called for Sealaska to lease these rights to the Greens Creek Joint Venture in return for a yearly lease fee to be negotiated and a 3.5-percent net smelter return royalty on any ore mined outside the existing core and perfected claims and extralateral rights from those claims. The lease would have a life of 25 years with mandatory work commitments made by the Greens Creek Joint Venture for each year. Sealaska saw themselves as a “passive” landowner (Birch, Horton, Bittner, Pestinger, and Anderson, written commun., 1985). This agreement hinged on at least a one-year extension of the exploration permit deadline to allow Sealaska adequate time to complete the land exchange.

The exchange with Sealaska Corporation was seen as the best option. The attorneys employed by Sealaska believed that the various environmental groups would support only this option. Litigation was unlikely since Sealaska, a Native corporation, was involved. Sealaska and the Sierra Club were trying to link the Greens Creek land exchange with another land-management dispute on Admiralty Island. The Shee Atika Native corporation was planning to harvest trees on the land at Cube Cove for which Sealaska owned the mineral rights. This clearcutting plan had the Sierra Club up in arms. Sealaska thought that the Sierra Club and the Forest Service would support a plan that halted the imminent harvesting (Birch, Horton, Bittner, Pestinger, and Anderson, written commun., 1985). However, Greens Creek wanted the issues resolved separately so that no additional complications would arise. Many groups, including the Shee Atika, the Alaskan congressional delegation, and the Greens Creek Joint Venture, were becoming increasingly dubious about Sealaska and their actions (Steven Silver, memorandum to P. Richardson, 1985).

The exploration permit was extended by one year in 1985. This allowed for continuing negotiations with Sealaska and further exploration to prove additional claims. By 1988 the USDA Forest Service rendered a decision denying the land-exchange proposal. The land exchange still could be completed if the agreement involved the surface rights to the Cube Cove land. This would require a direct agreement with the Shee Atika owners. Despite these problems, the Greens Creek Joint Venture felt that a land exchange opening the remainder of the Greens Creek area to subsurface mineral development was just a matter of time (T.C. Crafford, memorandum to H. Griffith, 1988).

Ownership Changes and Consolidation, Development, 1986–89

A major ownership change occurred at the beginning of 1986. Amselco (parent company, BP) purchased Noranda’s and Anaconda’s (which had just been liquidated by its parent company, ARCO) interest in the Greens Creek Joint Venture. That gave Amselco 70 percent of the total interest in Greens Creek, and they became the operators of the property. The geology staff did not change.

1986 Surface Exploration Program

The 1986 surface exploration program drilled surface and subsurface drill holes in an attempt to perfect four claims. Two of the claims (1001 and 1208) would be considered strike extension claims that Amselco believed, if allowed to patent, would extend their extralateral rights to the north and south (E.D. Harrison, Greens Creek Mining Company, written commun., 1986). The other two claims, 1104 and 1206, were believed to be covered under existing extralateral rights but were drilled anyway to test for downdip mineralization. Three surface holes were completed, totaling 4,694 feet, and one underground exploration hole was drilled to 1,271 feet.

The first hole drilled, PS–97, was the only one of major success. Two ore intervals were intersected consisting of mineralized gray chert and massive to semimassive sulfides. The lower intercept was at an elevation of 760 feet and was 25.9 feet long, averaging 0.08 troy ounce per ton gold, 16.68 troy ounces per ton silver, and 6.2 percent zinc. The rocks were unusual in that the mineralized chert was complexly folded and(or) interfingered with argillite, and the contact was 500 feet above the projection of the ore horizon in holes from the North and lower Central Ore zones. Ed Harrison believed the mineralization was continuous (E.D. Harrison, Greens Creek Mining Company, written commun., 1986); however, later drilling would define this as a separate ore zone, the Upper Southwest. The claim line between 1103 and 1104 had not been accurately surveyed and the ore horizon was right along the apparent boundary, thus making it difficult to prove the claim. The other two surface holes, PS–98 and PS–99, did not intersect mineralization on claims 1208 or 1206, respectively.

An underground hole was yet another attempt to prove claims to the south (1001) by drilling through the major fault at the end of the exploration drift. For the first 250 feet of hole GC–143, which corresponded to the faulted zone, 3.25-inch-diameter (PHR) core was taken, and then 2.5-inch diameter (HHR) core was taken to 411.3 feet. The core diameter was reduced to 1.875 inches (NQ) to 1,271 feet. The hole intersected ore grade intervals (up to 16.4 troy ounces per ton silver and 23.7 percent zinc), 3 to 100 feet wide, of mostly faulted white baritic ore (WBA) within argillite. This hole extended the known mineralization of the South Ore zone another 300 feet to the south into an unperfected claim.

Surface mapping and exploration were mostly limited to the Mammoth and Mariposite claim groups. The first occurrence of silver sulfides on Greens Creek Joint Venture lands was sampled in a 10-foot zone just to the north outside of the Mammoth claims. The sample assayed at 53.75 troy ounces per ton silver. Four diamond drill targets were outlined for drilling in 1987 on the Mammoth claims, as specified in the work commitment spelled out in the lease agreement (E.D. Harrison, Greens Creek Mining Company, written commun., 1986).

Tom Crafford’s 1986 map and report outlined his ideas and conclusions concerning Greens Creek geology. He verified through field evidence that the linear aerial photography features do represent major faults of probable right-lateral movement with possible oblique or reverse slip components (T.C. Crafford, written commun., 1987). The youngest cleavage identified (now defined as S_3) within the Greens Creek rock package is a fracture cleavage related to the above major faults. He believed the first structural event is manifested by the recumbent isoclinal folds (later described as the D_2 event). He further refined the Mammoth claim geology and thought that the previously exhalative explanation for the QCM (quartz-carbonate-mariposite) unit was incorrect. Field evidence supports the idea of the altered mafic tuffs grading into the QCM unit, thus being serpentinized mafics (T.C. Crafford, written commun., 1987).

Four EM and magnetic survey lines were flown over the Greens Creek area piggybacked on Amselco's Mansfield aerial geophysical survey. No magnetic anomalies were identified from the survey. However, 6 of the 11 EM anomalies coincided with soil geochemical anomalies in the Big Sore area (E.D. Harrison, Greens Creek Mining Company, written commun., 1986).

Underground work continued to define the orebody in greater detail and to test different drifting and grade-control practices. A footwall drift was extended 94 feet from the east rib of the 1981 ore crosscut. The 9-foot-wide by 8-foot-high drift driven by jacklegs tested for mining problems within argillite. Four 1.432-inch diameter (BX) core holes were drilled using a CP–65 pneumatic drill rig from the new footwall drift. Two holes were drilled from the 1981 ore crosscut. These holes were drilled at tight 10- to 15-foot spacings along the contact to obtain more detailed structural data than from the drilling at 150-foot spacings. Detailed sampling of this core was carried out to determine the actual ore-waste boundary. The contact between the ore and hanging-wall argillite was the most important contact to define because most of the high-grade precious metals were found within 6 to 18 inches of that contact (E.D. Harrison, Greens Creek Mining Company, written commun., 1986).

1987 Surface Exploration Program

The exploration permit for the Big Sore and Tom claim groups was not extended another year by legislative means. The Greens Creek Joint Venture lost all rights to the Big Sore claims except for the eight core claims and the nine additional perfected claims. Negotiations were continuing with the USDA Forest Service and Sealaska to work out a land-exchange agreement.

The 1987 program concentrated on prospects away from the Greens Creek mine area. The Mammoth claims received the bulk of the attention and funds. Four diamond drill holes were completed, totaling 1,441 feet (W.C. Meyers, written commun., 1988). Three of the holes tested the mineralization seen on the ridgetop exposure of the QCM unit, and one hole targeted the lower QCM band. All holes intersected minor mineralization over short (less than 3-foot) intervals, assaying up to 0.236 troy ounce per ton gold, 1.72 troy ounces per ton silver, and 3.8 percent zinc. The mineralization occurred within the QCM units for the ridge trend holes, while the mineralization occurred with the graphitic schist unit in the lower band. Six additional holes were outlined for drilling in 1988, mostly along strike of the graphitic schist/QCM contact.

Exploration work also was completed within the Fowler, Lil Sore, and Mariposite claim blocks. The first two claim groups were part of the original Norbritex Joint Venture. This joint venture was formed by Noranda, Bristol Bay, and Texas Gas in 1980 to explore lands outside of the Big Sore and Tom claim groups in which the other members of the Greens Creek Joint Venture did not wish to participate. Norbritex drilled one hole in Lil Sore that intersected a quartz-sericite unit overlying a graphitic unit, both thought to be part of the mine stratigraphy (W.C. Meyers, written commun., 1988). Soil sampling and CEM geophysics were carried out on soil grids to outline possible Greens Creek-type volcanogenic massive sulfide (VMS) targets or epithermal gold targets. Six anomalous soil geochemical zones were outlined, two of which occurred proximal to, or over, a sericitized pyrite breccia unit. Some of the soil anomalies had coincident CEM conductors. Additional soil sampling (in-fill), mapping, and trenching were recommended for these three claim groups.

The Greens Creek Joint Venture recognized the need for a better understanding of the structural geology of the mine, especially for mine planning. Three structural geology consultants (John Proffett, Ken McClay of the University of London, and Brian Marten of BP Minerals International) were contracted to perform separate structural studies. Marten's study was the first undertaken in early April of 1987. Marten deemed his results to be very preliminary by himself after he discovered that the 2 weeks he allotted for the study were "totally inadequate due to the unexpected structural complexity that was found" (B.E. Marten, BP Minerals International, written commun., 1987). He concluded that at least two intense penetrative shear deformational events were present that have been refolded by a third fold phase (D_1 through D_3). Marten believed that the first deformation had the greatest effect on the massive sulfides and result in milling, brecciation, and plastic flow. The hanging-wall breccia was also a result of this intense shearing (not phreatoclastic). He stated that the ore zone was likely a major shear zone. He expressed concern that the previous quantity and quality of structural observations underground, in drill core, and on surface were woefully inadequate for ore reserve calculations and mine planning (B.E. Marten, BP Minerals International, written commun., 1987).

John Proffett largely agreed with Marten's observations, though he did not see direct evidence for the first deformation event and he added a fourth, open-fold event (J.M. Proffett, written commun., 1987). He saw the second event to be the most intense, giving rise to S_2 axial planar to steeply plunging isoclinal F_2 folds. Gently south-southeast-plunging F_3 folds in turn fold F_2. He thought that the S_2 was nearly parallel to bedding. The S_2 foliation is the dominant foliation seen in all rock types (compositional banding within the phyllites and ore, and the slaty cleavage in argillite). He found no evidence for major thrust faulting along the ore/argillite contact. In addition, he mapped local F_4 folds that plunge nearly parallel to F_3. The structural nomenclature suggested by Marten and refined by Proffett is still accepted and used by mine geologists at Greens Creek. McClay also largely agreed with Marten and Proffett. He adds a later D_5 event to describe the later brittle faulting (K.R. McClay, University of London, written commun., 1987). His conclusion mirrored Marten's that the current structural database was inadequate, and more detailed work was necessary for ore reserve calculations and mine planning (K.R. McClay, University of London, written commun., 1987). Despite the inherent structural complexities at Greens Creek, all three geologists agreed on a structural framework that still stood in 2001.

1988 and 1989 Surface Exploration Projects

Development and preproduction projects took priority over the next 2 years. Greens Creek management was waiting for the finalization of a land-exchange agreement with Sealaska (Greens Creek Mining Company, written commun., 1988). The minimum assessment work was completed on the various claim blocks in 1988, mostly consisting of mapping and trenching. Work on the Mammoth claims included the completion of one diamond drill hole. MRD–5 was drilled 600 feet southeast of hole MRD–4, testing for sulfides along the quartz-carbonate/graphitic schist contact. The hole did intersect minor disseminated galena and sphalerite, though no assay numbers are reported.

The Greens Creek Life of Mine Plan was released on March 25, 1988. The plan called for the startup of production operations in early 1989 with concentrate being produced by that February. Full-production rate was expected to be 1,000 tons per day (TPD) operating 355 days a year. The mine life was expected to be 11 years. Total capital expenditures necessary for development and startup were reported as \$105.8 million, with another \$12.1 million expected over the life of mine.

This plan proved workable. The Greens Creek mill processed the first ore from the mine on February 5, 1989. This was achieved despite the ferry dock being severely damaged by a winter storm on January 30 (Greens Creek Mining Company, written commun., 1989). Crews were transported to and from the mine by way of helicopters and float planes until a temporary dock was installed on February 7. The mill processed 8,150 tons of ore during the first month of operations.

Surface exploration activities consisted of two holes drilled from Big Sore claim 1105, targeting downdip of the North Ore zone. PS–100 was abandoned after 456 feet due to poor drilling conditions. PS–101, drilled from the northwest corner of the claim, reached 2,106 feet and intersected three barren contacts. No record exists of any assessment work done on the outlying claims. One significant underground drilling discovery was made. Hole GC–265, drilled along section 33, intersected 235 feet of ore-grade massive sulfide at a lower elevation than that of the North Ore zone. This was an apparent new ore trend in a previously untested area (Greens Creek Joint Venture, written commun., 1994). This zone was later defined as the (Central) West zone.

Continuing Underground Exploration, Production to Shutdown to Reopening, 1990–95

The 1990 surface exploration campaign was very active after two summers of mostly minimum assessment work during startup. Diamond drilling took place on validated and unvalidated claims to the west of the established orebody. Drilling was allowed off the validated claims and within the national monument nonwilderness after the USDA Forest Service determined the Greens Creek Joint Venture had sufficient claim of extralateral rights (William Edwards, written commun.,1990). This final effort to validate claims to the west of the core claim group was the largest surface drilling project to date (10 holes totaling 23,287 feet).

The first hole, PS–102, was drilled at the same site as PS–100, which was abandoned the previous year. This hole did not intersect any economic mineralization. However, the next three holes all intersected ore from widely scattered drillpads. PS–103 was collared along the very southern edge of claim 1105 to test the possible southwest extension of the North Orebody. The hole intersected three ore-grade intervals along a contact between a siliceous breccia and argillite. The bottommost 5.5-foot intercept included visible electrum that ran 0.524 troy ounce per ton gold and 86.4 troy ounces per ton silver (J.G. Baughman, memorandum to T. Crawford, 1990). PS–104 was drilled 1,200 feet to the southeast of PS–103 and intersected two ore intervals, including 24 feet of 0.102 troy ounce per ton gold, 35.99 troy ounces per ton silver, and 9.1 percent zinc at the 860-foot level. PS–105, 500 feet from PS–103, tested the northwest extension of this mineralized interval. This hole intersected ore-grade massive sulfide at the 950- and 500-foot levels. The drill program geologists believed that the mineralization was continuous for over 1,600 feet, but they could not confidently correlate it with other recognized orebodies (J.G. Baughman, memorandum to T. Crawford, 1990). PS–103 and PS–105 were the first holes to intersect the Northwest West Ore zone on the west side of the Maki fault. The underground drilling program intersected significant base-metal intervals in hole GC–502, drilled from the 33 Exploration drift. This hole helped to define the Central West Ore zone as a separate orebody (Greens Creek Joint Venture, written commun., 1994). PS–104 intersected the top of what was later defined as the Southwest Ore zone.

Three more surface holes tested the extent of the mineralization intersected by GC–502: PS–108 and PS–110 to the south, and PS–109 to the west. Only hole PS–110 and a wedge drilled off the hole (PS–110a) intersected significant mineralization. A 16.1-foot-long ore-grade interval (2.11 troy ounces per ton silver, 16.69 percent zinc) was intersected deep (2,050 feet) in the hole. This pierced the 5250 orebody (a somewhat continuous satellite of the West Orebody). The other two holes of the 1990 summer program, PS–106 and PS–107, tested downdip (to the southwest) of the intersections in PS–103 and PS–105, respectively. Both holes intersected only stratigraphic footwall (phyllite) rocks.

The 1990 surface drilling program intersected three new orebodies: the Central West, the Northwest West, and the Southwest. Much more drilling from underground was needed before most of the structural complications could be solved and the three new orebodies roughly defined. The following 2 years involved a very aggressive underground drill program to define the Central West Ore zone on 100-foot centers. By the end of 1990, underground drilling had increased the indicated reserves from 3.6 million tons to 6.9 million tons (Greens Creek Joint Venture, written commun., 1990) of which 2.8 million tons were in the probable category (Kennecott Greens Creek Mining Company, written commun., 2001). No additional surface drilling took place until the passage of the Land Exchange Act in 1996.

Assessment work continued on the claim groups to the north, and minor geologic mapping and geochemical sampling took place within the AINM boundary. Two soil geochemistry grids were completed in Fowler Creek and the “L” zone along the Maki fault (Upper Zinc Creek), south of the Lil Sore grid. Only the “L” zone showed any geochemical anomalies (D.L. Lorge and others, written commun., 1990). Previously unidentified mineralization was sampled on Antenna Mountain, Zinc Creek Pass, and the Zinc Creek roadcut south of the Zinc Creek bridge (fig. 1). The latter was the most significant at 8.07 percent lead and 22.86 percent zinc.

A different geologic model for the Greens Creek deposit emerged from the geologic mapping and sampling completed during the summer. The surface crew consisting of David Lorge, Eric Lalechuer, and William McClelland felt that all the anomalous soils and surface mineralization occurred along major faults (D.L. Lorge and others, written commun., 1990). Their new deposit model envisioned these faults (presumably the northwest-trending Maki-type faults) as being the main ore control and horizons. They interpreted the faults as forming during metamorphism and formation of the S_2 foliation. These faults were structural channels for the intrusion of ultramafic plutons and replacement mineralization. In a separate report, McClelland (W.C. McClelland, written commun., 1990) suggests that the Greens Creek deposit is a replacement of Upper Triassic sediments associated with a hydrothermal system driven by Upper Triassic volcanic rocks and(or) Late Triassic hypabyssal mafic to ultramafic intrusions. He cited the presence of an Upper Triassic *Halobia* fossil within an ore-enclosed concretion as evidence of replacement of the surrounding sediments. He described that much of the mineralization observed in core and on surface was controlled by veins that crosscut the S_2 foliation. All of the workers felt confident that additional massive sulfide deposits could be discovered within the Upper Triassic units with exploration concentrated along suspected northwest-trending faults (D.L. Lorge and others, written commun., 1990).

1991 Exploration Program

Underground exploration and continued production were emphasized in 1991. Only the minimum amount of assessment work necessary for claim maintenance was completed on the surface. Underground drilling to define the West Orebody was successful and resulted in subdividing it into three distinct zones (Greens Creek Joint Venture, written commun., 1994). Drilling to the south and west of the projected trend of the West Orebody intercepted high-grade intervals in holes GC–738, GC–739, and GC–753 that further defined the Southwest Ore zone. Continued definition and exploration drilling underground to the south was given an additional boost when the Forest Service’s mineral examiner and council gave positive comments during a preliminary meeting discussing extralateral rights to the south of the Big Sore claim block (Greens Creek Joint Venture, written commun., 1991). The 1991 definition drilling campaign increased the ore resource to 13.0 million tons, an increase of 6.1 million tons (Kennecott Greens Creek Mining Company, written commun., 1991). The proven and probable reserves, however, dropped to 1.2 million tons (Kennecott Greens Creek Mining Company, written commun., 2001).

On-Line Exploration from Anchorage was contracted to complete the assessment work required for claim maintenance. Their work concentrated on the leased Mammoth claims and unpatented Mariposite claim block. A soil geochemistry grid just north of the Mammoth claims yielded two minor discoveries. The first was a barite-bearing outcrop with visible gold (J.E. Adler and others, On-Line Exploration Services, Inc., written commun., 1991). However, assays did not confirm anomalous gold. The other discovery was disseminated sphalerite, galena, and chalcopyrite within a quartz vein. Both mineralized occurrences had slight soil geochemical expressions. On-Line Exploration recommended drill testing on the “L” zone pyrite, previously mapped and sampled within the Mammoth claims (J.E. Adler and others, On-Line Exploration Services, Inc., written commun., 1991).

1992 Exploration Program

The 1992 surface exploration program consisted of diamond drilling to fulfill the annual assessment work requirements. Wink Drilling of Juneau was contracted to drill 2,000 feet on unpatented claims north of the AINM boundary (Greens Creek Joint Venture, written commun., 1992). Two drill holes, MC–1 and MC–2, tested a weak silver-zinc soil anomaly on the Mariposite claim group defined by the 1991 program. Both holes were abandoned before reaching the target depth and did not intersect any mineralized intervals. Drilling was completed on the HI East and HI West claims leased from NERCO on the Mansfield Peninsula with no success. The underground drilling program completed drilling of most of the West Ore zone on 100-foot centers.

Ed Harrison recommended dropping the Mansfield claim groups in order to focus resources on the Fowler, Lil Sore, Mariposite, and Big Sore claim groups. Harrison also advocated continued drilling on the Mariposite block and forming a Greens Creek joint venture exploration company with a separate budget from the mine because Kennecott Greens Creek Mining Company finances lacked the necessary funds to mount an effective exploration campaign (E.D. Harrison, memorandum to C. Davis, 1992).

Negotiations began on a new land-exchange proposal that only involved Greens Creek and the Forest Service. Greens Creek submitted a "bare-bones" proposal to the Forest Service in September of 1992. The proposal called for Kennecott Greens Creek Mining Company to purchase $1,375,000 worth of private land in-holdings on Admiralty Island and other areas of the Tongass National Forest and convey the land to the Forest Service in exchange for the subsurface mineral rights to 6,875 acres surrounding the core claims (Steven Silver, memorandum to R. Pierce and C. Davis, 1992). The agreement also called for a net smelter interest paid to the Forest Service for any minerals produced from the area. This item proved to be the most contentious in the negotiations. Congressional approval was necessary for any land exchange involving a national monument. Greens Creek finally received title to the 17 core claims and one millsite claim after the USDA Forest Service and Bureau of Land Management approved the final validity test in December, 14 years after the process had been initiated (Greens Creek Joint Venture, written commun., 1992).

1993 Closure

Kennecott announced in February 1993 that production mining and milling operations would cease by mid-April. The primary cause of the closure was low metal prices (Greens Creek Joint Venture, written commun., 1993). Greens Creek lost $2.2 million during the month of February alone. Milling ceased on April 10 and all but 24 employees were laid off by April 30 (Greens Creek Joint Venture, written commun., 1993). The remaining personnel were involved in the maintenance of permits and in development of the West Ore zone to satisfy the Forest Service's requirement of "use" of the property.

Underground diamond drilling began on July 17 to explore and define the Southwest Ore zone. The drilling occurred mostly from the 36 Exploration drift, which was being driven to the west of the 920 Main Haulage at the same time. Tim Hall was hired as the new Chief Geologist, and Deborah Apel returned to supervise the drilling program in November. A total of 30,261 feet was drilled along 200-foot spacings from section 3200 to 2400.

1994 Exploration

The Greens Creek Joint Venture agreed on November 17, 1993, that the Southwest Ore zone would require drilling at tighter (50-foot) spacings to adequately define the resource (Greens Creek Joint Venture, unpub. data, 1993). They approved a 120,000-foot drill program and initiated a feasibility program to explore and develop the Southwest Ore zone. Development continued in the 36 Exploration Drift to provide platforms for drilling. The drift passed through the southern boundary of the claim block in February. It was not until April that the Forest Service confirmed the assertion of extralateral rights that included the Southwest Ore zone (Greens Creek Joint Venture, written commun., 1994).

By the end of 1994, 130,803 feet of diamond drilling had been completed, mostly within the Southwest Ore zone (Greens Creek Joint Venture, written commun., 1994). Most of the drilling was accomplished on 50-foot spacings and centers. At the end of 1994 the recoverable ore reserve for the Southwest Ore stood at 2.4 million tons at 0.244 troy ounce per ton gold, 32.86 troy ounces per ton silver, 5.91 percent lead and 12.35 percent zinc (Greens Creek Joint Venture, written commun., 1994). The feasibility report called for startup of the mill by January 1, 1997, at a rate of 1,320 TPD using the higher grade Southwest ore. The plan also called for expansion to 2,000 TPD by 1999, with additional lower grade ore sourced from the West Ore zone.

The land-exchange agreement with the USDA Forest Service was signed in Washington, D.C., on December 17, 1994, after much bargaining over a sliding royalty scale based on net smelter return (NSR). A compromise was reached in September when Greens Creek accepted the Forest Service's sliding royalty of 3.0 percent for ore greater than $120/ton in exchange for reducing the $1.5 million in-holding purchase amount to $1.0 million (Greens Creek Joint Venture, written commun., 1994). A royalty of 0.5 percent was imposed on ore between $80/ton and $120/ton. The next step was to gain congressional approval through legislation.

Very little surface activity took place in 1994. Geologists from Kennecott Exploration completed a reconnaissance sampling program in the mine area and on Mariposite Ridge. Paul Lindberg began a 4-year stint as a consulting geologist to work on various projects, including geologic investigation of the Southwest Ore zone and interpretations and reconstructions along the Maki fault and other shears. Lindberg's interpretation of drillcore from the Southwest Ore zone led him to believe that much of the ore horizon was rooted in the argillite section and not at the argillite/phyllite contact (P.A. Lindberg, written commun., 1994). He also (re)identified the Klaus fault, which he believed decapitated the Southwest Orebody, displacing the top 700 feet to the northwest (P.A. Lindberg, written commun., 1994). The imminent completion of the land exchange led Lindberg to comment on future exploration. He proposed allowing a great deal of lead time to compile and digitize historical exploration data and maps that had been essentially archived for the past 4-plus years (P.A. Lindberg, written commun., 1994). Other ideas for initiating the exploration program were airborne geophysical and photometric surveys and liaising of the new exploration personnel with current geology staff.

The leased claims in HI East and HI West with NERCO were dropped as the area of Joint Venture was reduced to the lands south of Young Bay and east of Hawk Inlet (Greens Creek Joint Venture, written commun., 1994). The Joint Venture changed when Kennecott bought out CSX (Exhalas was bought out by the three remaining partners in 1993). The ownership split was 70.27 percent Kennecott and 29.73 percent Hecla.

Land Exchange Act and Continuing Production and Exploration, 1995–Present

The Greens Creek Land Exchange bill was introduced to the Resource Committee of the U.S. House of Representatives on March 16, 1995. The bill was cosponsored by Don Young (R-Alaska) and George Miller (D-California), who were usually on the opposite side of an issue from each other. The bill did not make it out of committee in 1995. Greens Creek employees received good news when the Kennecott Board of Directors, on April 5, 1995, approved the allocation of $87.3 million to reopen Greens Creek with production at 1,320 TPD (Greens Creek Joint Venture, written commun., 1995).

Paul Lindberg and Norm Duke of the University of Western Ontario completed a preliminary geologic mapping and sampling project in and around the Greens Creek mine in the summer of 1995 while the Greens Creek Land Exchange bill was in legislative limbo. They spent 2 weeks traversing various parts of the property, including the Mammoth claims, Cliff Creek (the area of the original geochemical anomaly leading to the discovery of Greens Creek), Gallagher Creek, Killer Creek, and along the road corridor. Duke concluded that the Greens Creek orebody was upgraded by remobilization of syngenetic lead-zinc-silver from the argillites (SEDEX model) and gold sourced from the strongly carbonitized mafic and ultramafic rocks (N.A. Duke, written commun., 1996). Duke subsequently refined and redefined his model based on his regional geologic mapping.

1996 Exploration and Reopening

The 12-year battle for gaining exploration rights to the original claim group finally ended on April 1, 1996, when President Bill Clinton signed the Greens Creek Land Exchange Act. Work began immediately on purchasing $1.0 million of private in-holdings, primarily from a list of preferred properties compiled by the USDA Forest Service. This process took nearly 2 years to complete.

Steve Newkirk was hired during the winter of 1995 to resurrect an active surface exploration program after a 7-year hiatus. Staking and filing 213 Federal lode claims in unclaimed holes south of Young Bay further refined the land picture. In addition, 15 State tideland claims were staked along upper Hawk Inlet. However, the State of Alaska also selected the land for potential community development and thus its status remains in limbo. The 10-year lease of the Mammoth claims expired at the end of 1995. Negotiations took place over several months with the owner, Herman Meiners, to renew the lease or to purchase the claims outright. However, Meiners did not budge from his high asking price and evidently shopped the property around to other potential buyers with no results (S.R. Newkirk, written commun., 1996). No further negotiations took place.

Surface diamond drilling was limited to the patented claim block until the land-exchange lands were fully conveyed. The Forest Service would allow only nonimpact activities such as helicopter landings, soil and rock sampling, airborne and ground geophysical surveys, and geologic mapping. The 1996 program initially involved one drill rig operated by Connors Drilling. However, poor advance rates due to poor ground conditions, frequent mechanical failures, and driller inexperience with Greens Creek-type conditions necessitated mobilizing a second drill rig.

Nine holes totaling 7,755.5 feet were completed. The first three holes, PS–111, PS–112a (abandoned after 487 feet), and PS–112, were collared from the 1350 adit access road and targeted the possible northwest extension of the North Ore zone. Neither completed hole intersected significant mineralization. PS–113 through PS–117 were drilled from three drillpads targeting the Upper Plate Extension of the Northwest West Ore zone (the Maki offset on the west side of the West Ore zone). This thin, flat-lying mineralized horizon had been intersected in a few holes from underground but was not systemically explored. PS–115 had the only significant intercept, a 1.5-foot interval of ore running 0.16 troy ounce per ton gold, 19.44 troy ounces per ton silver, 3.4 percent lead and 6.8 percent zinc. PS–118 targeted the possible north extension of the West Ore, first intersected by PS–87 in 1984. The hole was located 600 feet north-northeast of PS–87 and did not intersect mineralization.

Numerous geophysics methods were tested at Greens Creek to determine which might be more effective in surface exploration. Airborne EM, radiometric, and magnetometer surveys were completed in conjunction with Kennecott Exploration's Mansfield project. The surveys, carried out by Aerodat, flew more than 1,200 kilometers of line that covered the entire Greens Creek area, including the land exchange. Distinct magnetic anomalies corresponded with already mapped ultramafic bodies (for example, Killer Creek serpentinite). The EM survey proved useful in identifying graphitic rocks, such as the Hyd argillite. Underground and surface gravity surveys were completed. The underground survey, extending from the portal to the end of the 36 Exploration drift, detected a subtle ~1.5-Mgal anomaly over the West Ore zone. The surface survey over the Northwest West Ore zone failed to detect any coincident anomaly. Two test lines over the West and Northwest West Ore zones were surveyed by the CSAMT (controlled source audio-magnetotelluric) method. A resistivity low associated with the Northwest West Ore zone and Maki fault was detected, but the West Ore zone was not. A time-domain electromagnetic (TEM) survey was also completed over eight lines in the same area and measured a strong response from the West Ore. Downhole TEM surveys were completed on surface and underground holes. GC–1530, an underground exploration hole, produced a strong EM anomaly within the West Ore. This geophysical test work was done to develop the tools for a multiyear exploration program (S.R. Newkirk and others, written commun., 1996).

Norm Duke and Paul Lindberg completed reconnaissance and detailed geologic mapping and sampling within the land-exchange boundary. Their work culminated in a completely revised 1 inch=1,000 foot scale district map and numerous 1 inch=200-foot scale mine geologic maps. The prospective mine stratigraphy was traced to the south and north (S.R. Newkirk and others, written commun., 1996). The land-exchange boundary survey was finalized in November. Kennecott Greens Creek Mining Company developed a cooperative research agreement with Cliff Taylor of the USGS for a program to focus on many of the outstanding geologic problems of the Greens Creek mine (reported in this volume).

The work completed in 1996 was designed to lay the groundwork for a multiyear exploration program. The geologic mapping and research agreement was to refine the geologic model for the deposit. A GIS system, using ArcView software, was set up to aid in organizing the 20+ years of data. Historical geologic maps and geochemistry were digitized for the GIS project during the summer and fall.

Underground exploration was limited to definition drilling in the Northwest West and 5250 Ore zones. Preproduction drilling, consisting of horizontal fans of short (100- to 400-foot) holes, was carried out from various ore accesses in the Southwest Ore zone. These holes drilled on 10- to 25-foot centers aided in stope planning. The recommissioned mill began running ore from the Southwest orebody in July 1996. Kennecott Greens Creek Mining Company produced about 143,000 tons of ore averaging 0.108 troy ounce per ton gold, 23.80 troy ounces per ton silver, 4.84 percent lead, and 10.3 percent zinc. Almost all of the ore was sourced from the Southwest Ore zone.

1997 Exploration

Surface exploration activities were accelerated on the land-exchange property. Seven new grids totaling 230,000 linear feet, were cut and sampled within the Greens Creek Joint Venture lands. The grids within the land exchange included High Sore, Bruin, Lower Zinc, Upper Zinc, and Gallagher. The "A" Road and East Lil Sore (fig. 1) were cut within the unpatented claim groups north of the land exchange. Detailed work along each grid included soil sampling, gravity, magnetic and TEM geophysical surveying, and geologic mapping. No high-priority, near-surface coincident gravity and TEM anomalies (possible shallow massive-sulfide bodies) were identified (S.R. Newkirk and others, written commun., 1997). Soil sampling and geologic mapping outlined drill targets or areas for detailed followup work in Bruin, Gallagher, and Lower Zinc Creeks. The "A" Road prospect was discovered in 1995 during the road traverse of Paul Lindberg and was thought to be a possible distal "mine" horizon with exhalative quartz, barite, and pyrite (P.A. Lindberg, written commun., 1997). Work in 1997 defined soil anomalies coincident with the exhalative horizon, but convincing evidence was not found to determine whether or not it was the mine horizon. Norm Duke and Paul Lindberg completed reconnaissance scale and detailed geologic mapping. John Proffett returned for the first time since 1987 and carried out structural mapping. Lindberg completed detailed mapping of the road corridor and borrow pits, all of which was compiled in a 15-sheet map folio (P.A. Lindberg, written commun., 1997).

Four diamond drill holes totaling 6,316 feet were completed in 1997. All were drilled from pads constructed on patented Big Sore claims because the land exchange had not been conveyed. Hole PS–119 targeted the lower phyllite-over-argillite contact 800 feet to the northwest of hole PS–87. Only scattered zinc mineralization was intersected in the phyllite, and two argillite intervals intersected were clearly fault-bounded and nonmineralized. PS–120 targeted the same contact, except to the north-northeast (200 feet due east of PS–118). The hole did not intersect the contact, but a downhole TEM survey mapped a steeply dipping conductor to the southwest of the hole and a subhorizontal conductor 200 feet below the hole. This hole was reentered in 1998 to test the deeper conductor but did not intersect an interval corresponding to the conductor. PS–121 and PS–122 were collared in Big Sore claims 1305 and 1304, respectively, in the Gallagher Creek grid/prospect. Both holes intersected semimassive to massive pyrite and sphalerite zones with up to 9 percent zinc over 2-foot intervals. Mineralization in PS–122 occurred at and below a contact between graphitic phyllite and chloritic phyllite, which was thought to represent a new mineralized horizon at a different stratigraphic horizon (S.R. Newkirk and others, written commun., 1997). The surface drill program was cut short by a new discovery underground.

Discovery of the 200 South Ore Zone

Preproduction drilling continued to be a major portion of the underground drilling program. During December1996, a preproduction fan was drilled from the 200 Ore Access, targeting the 164-foot level. The southernmost hole, PP0204, intersected ore widths showing that the orebody was still open to the south of cross section 18, previously modeled as the end of the Southwest Ore zone. No additional preproduction holes were drilled to the south to find the terminus of the ore because of the oblique drilling angle. The 200 South stope (at the 164-foot level) began mining from the ore crosscut shortly afterwards. The 200 South stope reached section 18, the end of the ore reserve for that level, but still showed a full face of ore. Expecting the ore to terminate at any time, mining continued on a round-by-round basis for another 300 feet. At the same time, exploration drilling to the south commenced from the 480 Exploration drift. Hole GC–1632, drilled along section 16, intersected a 42-foot interval of zinc-rich massive ore about 200 feet below the 200 South stope. Kennecott Greens Creek Mining Company geologists quickly realized that the 200 South stope was the proverbial tip of the iceberg. Four drill rigs (including a diesel-powered surface drill rig) were mobilized to quickly define this new ore zone, named the 200 South orebody. Two drill rigs were positioned in the 480 Exploration drift and the other two in the 200 South stope, to drill the zone from the inside out. Long-section drilling from the face of the stope indicated that the ore zone continued to at least section 11. Drilling from the south extension of the 480 Exploration (4711 Drift) continued from 1998 through 2000 and defined a reserve of 2.08 million tons at 0.189 troy ounce per ton gold, 21.29 troy ounces per ton silver, 5.15 percent lead, and 12.50 percent zinc. Discovery and definition of the 200 South orebody drastically changed the mining schedule of the various ore zones. Due to the higher grade of the 200 South ore, it was mined ahead of the more accessible West Ore zone(s). The 200 South orebody accounted for 42 percent of the total mine production from 1998 to 2000.

1998 Exploration

The 1998 exploration program was boosted with the completion of the land exchange on August 5, 1998. The combined holdings of the Greens Creek Joint Venture now included 445 unpatented lode mining claims, 58 unpatented millsite claims, 17 patented lode claims, 1 patented millsite claim, and land-exchange lands totaling 17,617 acres. Drilling was completed on lands off of the validated claim block or extralateral rights assertions for the first time since 1985. Four holes (PS–124 through PS–127) were drilled in Bruin Creek, targeting the downdip potential of the north-striking phyllite-over-argillite contact. PS–124 and PS–125 were drilled from the same site as PS–47 and tested downdip and updip, respectively, from the semimassive sulfides intersected near an argillite/phyllite contact in that hole. Both holes intersected only minor mineralization in the upper phyllite unit. Both holes terminated in altered ultramafic rocks below a carbonate-rich contact zone with argillite. PS–126 was drilled near treeline in upper Bruin Creek to test coincident soil and TEM anomalies. The hole intersected a barren phyllite/argillite contact at 1,275 feet and terminated in a gabbro at 1,724 feet. PS–127 was drilled from the site of PS–81, drilled in 1984 by Noranda. This hole intersected two fault-controlled blocks of argillite with no sulfides. The only other hole drilled (besides the reentry of PS–120) was PS–123 in Gallagher Creek, testing the phyllite stratabound zinc-rich zone intersected in PS–46 and PS–122. Minor sphalerite and chalcopyrite were intersected, but to a lesser degree than in holes PS–46 and PS–122, indicating that the mineralization decreases to the southwest (A.W. West and others, written commun., 1999).

One new grid (Upper Big Sore) and extensions of three 1997 grids (Lower Zinc, Bruin, and “A” Road) were geochemically sampled and geophysically surveyed in 1998. The work outlined numerous multielement anomalies with coincident TEM anomalies, but none were significant enough to warrant immediate drilling (A.W. West and others, written commun., 1999).

John Proffett extended his 1997 mapping in the Big Sore area toward the 920 portal and west of the Maki fault. He also reviewed surface drill core from both sides of the Maki fault. He found evidence for a major shear zone (Upper Shear Zone) that juxtaposes nonmine-type slates, silts, and phyllites of uncertain age over mine-type argillites, phyllites, and ultramafic rocks (J.M. Proffett, written commun., 1998). Subsequent work in 1999 defined a deeper shear zone (Lower Shear Zone). These two shear zones bracket the mine stratigraphy (J.M. Proffett, written commun., 1999). The amount and direction of offset along the two shear zones and the stratigraphic position of the upper-plate rocks remain outstanding and important questions for surface exploration.

1999 Exploration Program

1999 was the first exploration season entirely focused in the land exchange. However, the season began poorly when the contracted Bell-206 helicopter crashed into the mill during takeoff on the first day of service. Fortunately, no one was seriously hurt. Two new geochemical grids were completed and one extended. A large grid was surveyed in Killer Creek, spanning 8,000 feet from the “B” Road to the Mammoth claims. Numerous high-rank, multielement soil anomalies were defined, and numerous sulfide-bearing outcrops and gossan zones were sampled and mapped. A new grid was cut in Cub Grid, just east of Bruin Creek. Two sets of major right-slip faults repeat the argillite/phyllite contact several times in Cub Creek. Anomalous geochemistry was coincident with an inferred contact zone in upper Cub Creek, near the land-exchange boundary (A.W. West and others, written commun., 2000). The Upper Zinc grid of 1997 was extended to the west. No significant discoveries were made in Upper Zinc Creek. However, two significant base-metal mineralized outcrops were sampled and mapped by Norm Duke to the southwest in the Lakes District prospect (N.A. Duke, written commun., 1999). One of the occurrences is near the contact between chlorite phyllite and possible Triassic carbonate rocks.

Ten diamond drill holes were completed totaling 12,715 feet. Seven of the holes were drilled in Bruin Creek. PS–128, PS–129, and PS–130 were drilled from the backslope directly behind (north of) the 920 administrative building. A shallow southwest-dipping barren phyllite-over-argillite contact was intersected in all three holes. PS–128 drilled through Proffett’s Lower Shear Zone and into more than 1,000 feet of ultramafic rocks. PS–131, PS–133, PS–137, and PS–138 were collared from two different pads on the west side of the mapped contact in middle Bruin Creek, about 1,000 feet east of the 1998 drill holes. Only PS–137 intersected conformable argillite/phyllite contacts. PS–136 was collared on the east side of the contact and also intersected the contact. In both holes, the contact was intersected multiple times, but no indication of mineralization was found. Three holes were drilled in Killer Creek. The first two holes, PS–132 and PS–134, were collared from the site of PS–20, drilled in 1977. Both holes intersected long intervals of semimassive to massive pyrite bands with minor sphalerite up to 15 feet wide within greenstones and serpentinites. PS–132 also intersected a deep (800 feet below the surface), fault-bounded, 3.6-foot band of massive chalcopyrite that ran 4.2 percent copper. PS–135 was drilled from a pad constructed above Pit 405, at mile 7.6 of the "B" Road. This hole intersected long intervals (up to 15 feet) of patchy zinc mineralization in chloritic phyllites.

2000 Surface Exploration

Two new prospects were drilled in 2000. Two pads were constructed in Cub Creek to test soil anomalies coincident with the phyllite/argillite contact. The targets were further refined by a CSAMT geophysical survey along three lines in Bruin and Cub Creek (three lines were also surveyed in Killer Creek). Results from the survey were of better quality than the 1996 survey due to better location of the transmitter line. The four holes drilled in Cub Creek (PS–144, PS–145, PS–147, and PS–151) did not intersect any significant metal enrichment along the contacts intersected. Data collected from these holes and two others (PS–147 and PS–148) in East Bruin Creek aided in the interpretation of the Bruin and Cub Creek regions. A large-scale recumbent syncline (cored by argillite) that closes to the west-southwest was found to be the dominant structure (A.W. West and others, written commun., 2001). The nearly isoclinal fold has mineral potential along both upper and lower limbs.

The Lower Zinc Creek prospect was drill tested for the first time from a pad constructed at the 2.8-mile mark of the "B" Road. Holes PS–152 and PS–153 were drilled to the northeast, targeting the mine contact. The contact intersected in both holes was strongly silicified and sulfidized (massive bands of pyrite). The geochemical results were highly anomalous in Ag, As, Hg, Ba, and Tl. Due to the mine lithologies intersected, abundant pyrite, silica alteration, and a distal geochemical signature, the potential of the Lower Zinc Creek prospect was upgraded (A.W. West and others, written commun., 2001).

Five holes were drilled in Killer Creek. The first two holes, PS–139 and PS–142, targeted a northwest-striking zone of zinc-rich, poorly exposed gossan. Both holes were abandoned in a wide fault zone (middle Gallagher fault) before reaching their target depth. Three holes drilled from two platforms in middle Killer Creek targeted a deep phyllite-over-argillite contact inferred from the CSAMT survey. None of the holes intersected argillite. However, all three did intersect fault-controlled secondary mineralization within 400 feet of their collars. Four moderately southwest-dipping zones with silver and zinc enrichment were defined with assays as high as 22.4 troy ounces per ton silver and 9.62 percent zinc (A.W. West and others, written commun., 2001). The intervals did not have sufficiently consistent grades or widths to be of economic significance.

Conclusion

For more than three decades, exploration, development, and production at the Greens Creek mine has been challenging. Fourteen years passed between the discovery drill hole intersecting over 80 feet of massive sulfide and the mill processing the first ore. During that time Greens Creek nearly became a casualty of a large conservation movement that included the White House and Congress. This movement culminated in the passage of ANILCA, which at first threatened to kill the project and then severely limited the land position at Greens Creek. Greens Creek emerged from this situation as an apparent incongruity: a mine within a national monument bordering a wilderness area. However, exploration for new orebodies from the surface effectively ceased. After 12 years of negotiations on local, State, and Federal levels, the land position was remedied in 1996 with signing of the Land Exchange Act. This unique act supported by conservation/environmental groups and industry alike increased Greens Creek's land position to what it was previous to ANILCA and added to the federally protected lands in the Admiralty Island National Monument and elsewhere in Alaska.

Exploration from the surface and underground has been successful in adding to Greens Creek's known reserves during the life of the mine. The nearly constant changes in ownership, personnel, and geologic models did not prevent new orebodies or extensions from being discovered. When low metal prices temporarily closed the mine in 1993, the high-grade Southwest Ore zone was discovered and drilled out. This new orebody allowed Greens Creek to reopen profitably in 1996. Since reopening, new reserves have kept pace with production, adding nearly 4 million tons of ore. The mine's proven and probable reserves, as of the end of 2001, are 7.6 million tons grading 0.133 troy ounce per ton gold, 16.67 troy ounces per ton silver, 4.57 percent lead, and 11.63 percent zinc (Kennecott Greens Creek Mining Company, written commun., 2001). The newly (re)acquired land-exchange lands provide abundant opportunities for future discoveries.

Reference Cited

Nash, Roderick, 1982, Wilderness and the American mind, 3d ed.: New Haven, Conn., Yale University Press, 425 p.