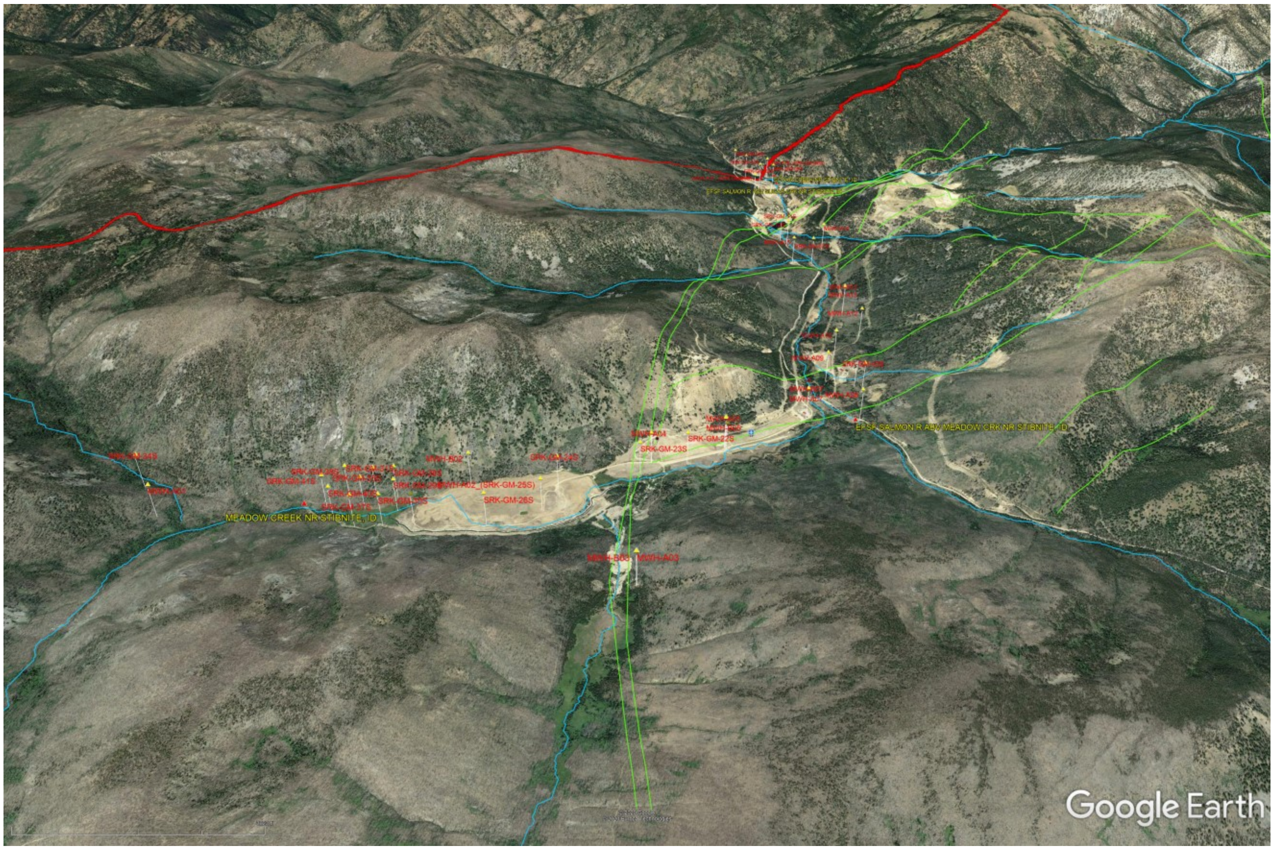
# Review of Hydrologic Impacts
# Of the Proposed Stibnite Gold Project
# Draft Environmental Impact Statement (DEIS)
# August 2020



September 16, 2020

Prepared by
Robert H. Prucha, Phd, PE
Integrated Hydro Systems, LLC
Boulder, Colorado

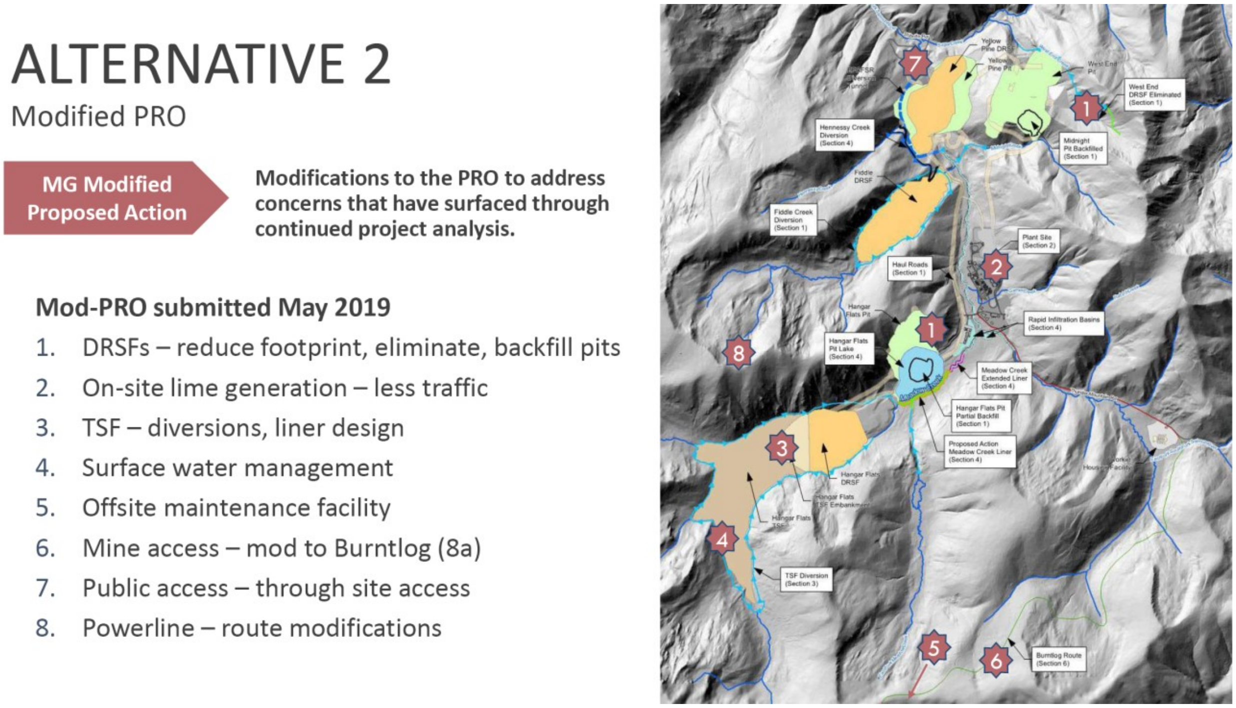
## 1 Introduction

My review of the Stibnite Mine DEIS and associated documents focused on evaluation of estimated surface water and groundwater hydrologic impacts of the proposed mining with emphasis on the following:

- Were baseline (Existing Conditions) hydrologic flow conditions adequately characterized and conceptualized?

- Were the range of predicted impacts to hydrologic conditions and water management (during mining and post-closure) physically realistic, defensible and justified, given the range of uncertainty in model inputs and assumptions? Specific areas of interest include:

    - East Fork of the South Fork of the Salmon River (EFSFSR),
    - Impacts of tunneled/lined streams (Meadow Creek and EFSFSR)
    - TSF – Meadow Creek (Proposed Action and Modified Proposed Alternative) and ESFRSR Alternative TSF-DRSF
    - TSF/DRSF/Pit Stream Diversions/Tunnels
    - DRSFs – Fiddle Creek, Hangar Flats, Midnight Pit, Yellow Pine
    - Pit dewatering – West End, Yellow Pine and Hangar Flats
    - Post-Closure Pitlakes – West End and Hangar Flats
    - Rapid Infiltration Basins



ALTERNATIVE 2

Modified PRO

**MG Modified Proposed Action**

**Modifications to the PRO to address concerns that have surfaced through continued project analysis.**

**Mod-PRO submitted May 2019**

1. DRSFs – reduce footprint, eliminate, backfill pits
2. On-site lime generation – less traffic
3. TSF – diversions, liner design
4. Surface water management
5. Offsite maintenance facility
6. Mine access – mod to Burntlog (8a)
7. Public access – through site access
8. Powerline – route modifications

I reviewed the following DEIS documents:

| **Reference Herein** | **Reference DEIS Document** |
|---|---|
| *B&C 2018 Existing Conditions* | EC report - BC (Brown and Caldwell), 2018a, Stibnite Gold Project Hydrologic Model Existing Conditions Report, Final, prepared for Midas Gold Idaho, Inc., April. |
| *ERM 2019 Peer Review* | Environmental Resources Management (ERM), 2019 Review of Surface Water and Groundwater Modeling for the Midas Gold Existing Conditions and Proposed Action. |
| *B&C 2019 Sensitivity Analysis* | Brown and Caldwell, 2019 Stibnite Gold Project - Hydrologic Model Sensitivity Analysis. December 09, 2019. |
| *HydroGeo 2012 SW Hydro Baseline* | HydroGeo, Inc., 2012 Draft Surface Water Hydrology Baseline Study for Golden Meadows Project. June 2012. |
| *B&C 2017 Water Resources Summary* | Brown and Caldwell, 2017 Stibnite Gold Project Water Resources Summary Report. June 30, 2017. |
| *BC 2019 Alt TSF/DRSF* | Brown and Caldwell, 2019 East Fork South Fork Salmon River TSF/DRSF Alternative Modeling Report. August 2019 |
| *BC 2018 Final PA* | Brown and Caldwell, 2018 Revised Final Stibnite Gold Project Hydrologic Model Proposed Action Report. Prepared for Midas Gold Idaho, Inc. October 2018. |
| *BC 2018 Final SPLNT Existing Conditions* | Brown and Caldwell, 2018 Final Stibnite Gold Project Stream and Pit Lake Network Temperature (SPLNT) Model Existing Conditions Report. |
| *BC 2019 Final SPLNT PA/Mods* | Brown and Caldwell, 2019 Final Stibnite Gold Project Stream and Pit Lake Network Temperature (SPLNT) Model Proposed Action and Proposed Action with Modifications Report. Prepared for Midas Gold Idaho, Inc. Revised March 2019. |
| *BC 2019 Final Mod PRO* | Brown and Caldwell, 2019 Final Stibnite Gold Project Modified PRO Alternative Modeling Report. Prepared for Midas Gold Idaho, Inc. September 2019. |
| *SGP 2020 DEIS Chapter 3 or Chapter 4* | USFS, 2020. Stibnite Gold Project Draft Environmental Impact Study. August 2020. Chapter 3 or Chapter 4. |
| *SPF 2017 SGP GW Hydro Baseline* | SPF Consulting and Associates (SPF), 2017 Stibnite Gold Project: Groundwater Hydrology Baseline Study. Prepared for Midas Gold, June 2017. |
| *TT 2019 Reclamation and Closure Plan* | Tetra Tech, Inc., 2019 Reclamation and Closure Plan (RCP), Stibnite Gold Project – Errata. Valley County, Idaho. Prepared for Midas Gold Idaho, Inc. July 26, 2019. |

## 2 Main Findings

Numerous concerns were identified in this review of the Stibnite Gold Project (SGP) Draft Environmental Impact Statement related to technical analysis of baseline hydrologic conditions, and predicated changes to these conditions as a result of the proposed mining and post-closure configurations. Key findings include the following:

1) Virtually all predicted impacts to the existing hydrologic system conducted in the DEIS, rely heavily on a modified version of the loosely-coupled surface water balance spreadsheet tool with a Modflow groundwater flow model, calibrated against baseline, or Existing Conditions (EC). **This review finds a number of significant issues at every stage of development the baseline hydrologic model (or EC model herein) development.**
    a. Analysis Methodology and Objectives Issues (see Section 4.1)
    b. Insufficient Data (see Section 4.3)
    c. Limited/poor/flawed Characterization (see Section 4.4)
    d. Conceptualization Poor/Unjustified/Flawed (see Section 4.5)
    e. Inadequate Hydrologic Codes Used (see Section 4.6)
        i. Assessment of hydrologic impacts and water balance estimates in the DEIS are unreliable because methodologies used are overly-simplistic, based on incorrect model inputs and assumptions, and key details and documentation are not provided. Digital model input files should have been provided for public review and transparency. Model predictions should not be relied upon in the DEIS.
    f. Model development/setup is flawed (see Section 4.7)
    g. Calibration of the Existing Conditions model is flawed in several ways that substantially limit its reliability and accuracy (see Section 4.8)
        i. Calibration didn’t consider mining impacts, or faults, both known to exist in the area and affect hydrology in various ways.
        ii. Calibration data are highly biased, and many available hydrologic datasets were not used to calibrate the model, including transient head data.
        iii. The B&C 2018 EC model used excessively low storage terms for the alluvium and fractured/non-fractured bedrock, which would:
            1. increase dewatering rates to remove water from storage.
            2. Result in longer pit dewatering times, and refilling of pitlakes
            3. Likely affects storage issues w/things like RIBS, which likely affects stream temperature predictions.

Because of the importance of developing the baseline EC model to all subsequent model predictions of specific mine impacts and water management that rely on this model, a fully integrated model was developed here to independently assess the validity of various inputs, assumptions and conclusions of the EC model (see Sections 3 and 5). Key findings of the integrated modeling suggests:

   a. An alternative, more realistic/defensible underlying overburden/bedrock configuration (layering/hydraulic properties) appears to better reproduce EC hydrologic conditions,
   b. Estimated flows for key water balance processes deviate notably from the DEIS EC model.
   c. A year-2100 climate change simulation shows notable hydrologic changes that should be addressed by the proposed mine plans/DEIS.

2) Baseline model errors and uncertainties directly translate into every prediction made using the modified baseline model and raise serious concerns about the reliability/accuracy of all subsequent predictions. Section 4.9 presents examples of affected predictions, which include:
   a. Dewatering
   b. Impacts to GDEs
   c. Post-Closure
   d. DRSF/TSF underdrain flows
   e. RIBs
3) A formal, industry standard predictive model uncertainty analysis was not performed in the DEIS, but should have given the high level of uncertainty in model inputs and assumptions.
   a. As a result, a full range of equally possible impacts to surrounding hydrology is not presented, discussed, or acknowledge in the DIES. A major implication of this is that the proposed SGP mine design, operation and post-closure configuration could have a much higher impact than presented in the various model-related evaluations,
   b. Substantial predictive model uncertainty wasn't accounted for in the proposed water management plan, or proposed action or MOD PRO plans. For example, if dewatering rates are double what is presented, the DEIS should have considered how these estimates would change the mine design/operation.
   c. The B&C 2019 Sensitivity Analysis didn't assess sensitivity wasn't performed using the MOD PRO assumptions/configuration. The sensitivity analysis is highly biased, and misleading in suggesting a range of predictive uncertainty.
4) Important analyses were not evaluated in the DEIS, but would significantly affect predictions of mine impacts, both during mining and post-closure:
   a. Climate change effects
   b. Post-fire flooding effects

The DEIS needs to develop more rigorous/realistic and well-justified EC model, and redo predictions, and assess the range of predictive uncertainty according to industry standard methods. The DEIS needs to then evaluate each proposed alternative mine design, operations and water management that consider the FULL range of predictive uncertainty, including the more conservative hydrologic conditions (i.e., account for the full range of possible dewatering rates/durations, larger temperatures, larger areal impacts, lower infiltration capacities in RIBs etc) and appropriate mitigations.

## 3 Development of Fully Integrated Hydrologic/Hydraulic Model to Assess SGP Model Setup/Results

The primary tools used to reproduce existing conditions and estimate predicted hydrologic impacts of the mine and post-mine conditions utilize on a single-process Modflow groundwater flow model, that relies on monthly-timestep external boundary inflows estimated using a simplistic/lumped-parameter spreadsheet-based 'meteoric water balance' (MWB) method. Supporting methodology is never presented, and the coupling of Modflow with the MWB spreadsheet tool reveal a number of inconsistencies and flaws (see Sections 4.6 through 4.9 below), both in the attempt to reproduce Existing Conditions (EC), or historical observed (or measured) flow conditions, and then in estimating future mine-impacted conditions. This represents a major deficiency in DEIS analysis, as the focus of the EIS is to accurately and realistically (i.e., hourly impacts vs. monthly) assess all impacts to the surrounding environment.

In summary, these tools are simply unable to simulate physically-realistic complex, spatially-/temporally-variable, dynamically coupled surface water-groundwater baseline hydrologic conditions, essential to demonstrating defensible and reliable predictions of impacts of mining during and post-closure. Importantly, any flaws identified in developing a model capable of reproducing baseline conditions will be translated into all subsequent models used to predict mine hydrologic impacts, but also water quality/geochemistry impacts, including thermal impacts (See Figure 1).

Given the importance of developing a defensible/accurate hydrologic model of baseline conditions, a fully integrated (coupled) hydrologic model based on DHI's MIKESHE/MIKEHydro software[1] was developed in this review (see Section 5) to further assess the adequacy of the baseline hydrologic model (B&C 2018 Existing Conditions) for use in the DEIS.

Though the intent here is not to promote a single software code, it's worth noting the following:

- many fully integrated, physically-based codes are readily available[2,3,4],
- they are increasingly used in mining problems world-wide[1],

---

[1] Wobus, C., R. Prucha, D. Albert, C. Woll, M. Loinaz, R. Jones, and C. Travers. 2015. Hydrologic alterations from climate change inform assessment of ecological risk to Pacific salmon in Bristol Bay, Alaska. PLoS ONE. doi: 10.1371/journal.pone.0143905.

[2] Taghavi, A., Namvar, R., Najmus, S. and Cayar M., 2013. Integrated Water Resources Models to Support Analysis of Integrated Regional Water Management Programs in California, British Journal of Environment & Climate Change 3(3): 333-377.

[3] AquaResource Inc. 2011. "Integrated Surface and Groundwater Model Review and Technical Guide." For The Ontario Ministry of Natural Resources.

[4] http://environment.alberta.ca/apps/emw/PresPost/CEM.aspx

- they avoid many of the limitations of simpler, single-process codes like those used here (i.e., decoupled, single-process, overly-simplified, non-physically-based), and
- they have distinct advantages of simulating physically-based and dynamic movement of water within the entire hydrologic system (all water entering the system is explicitly accounted for), and seamless flow between processes, and
- they are driven by sub-daily distributed **hourly** weather inputs, in a physically-based, fully-coupled, fully-distributed, and fully dynamic manner. Important processes like recharge and surface runoff are calculated internally, based on many dynamic and complex spatially-distributed parameters, which avoids significant errors introduced by using simpler representations of these processes.

Ultimately, these tools permit direct evaluation of important changes to the hourly **climate-driven fully-coupled hydrologic** response of the system to proposed mining-related changes to the land surface, vegetation, surface soils, subsurface pit, and surface drainage network, including effects of climate change at a timestep essential for evaluating impacts to fish, fish habitat/wildlife **(i.e., hourly to daily rather than at monthly timesteps)[5].**

---

[5] Prucha, B., Graham, D., Watson, M., Avenant, M, Esterhuyse, S., Joubert, A. Kemp, M., King, J., le Roux, P., Redelinghuys, N., Rossouw, L., Rowntree, K., Seaman, M., Sokolic, F., van Rensburg, L., van der Waal, B., van Tol, J., Vos, T. MIKE-SHE integrated groundwater and surface water model used to simulate scenario hydrology for input to DRIFT-ARID: the Mokolo River case study. Water SA 2016, 42 # 3, 384-398. https://www.ajol.info/index.php/wsa/article/view/141188 Accessed 6/28/2020.

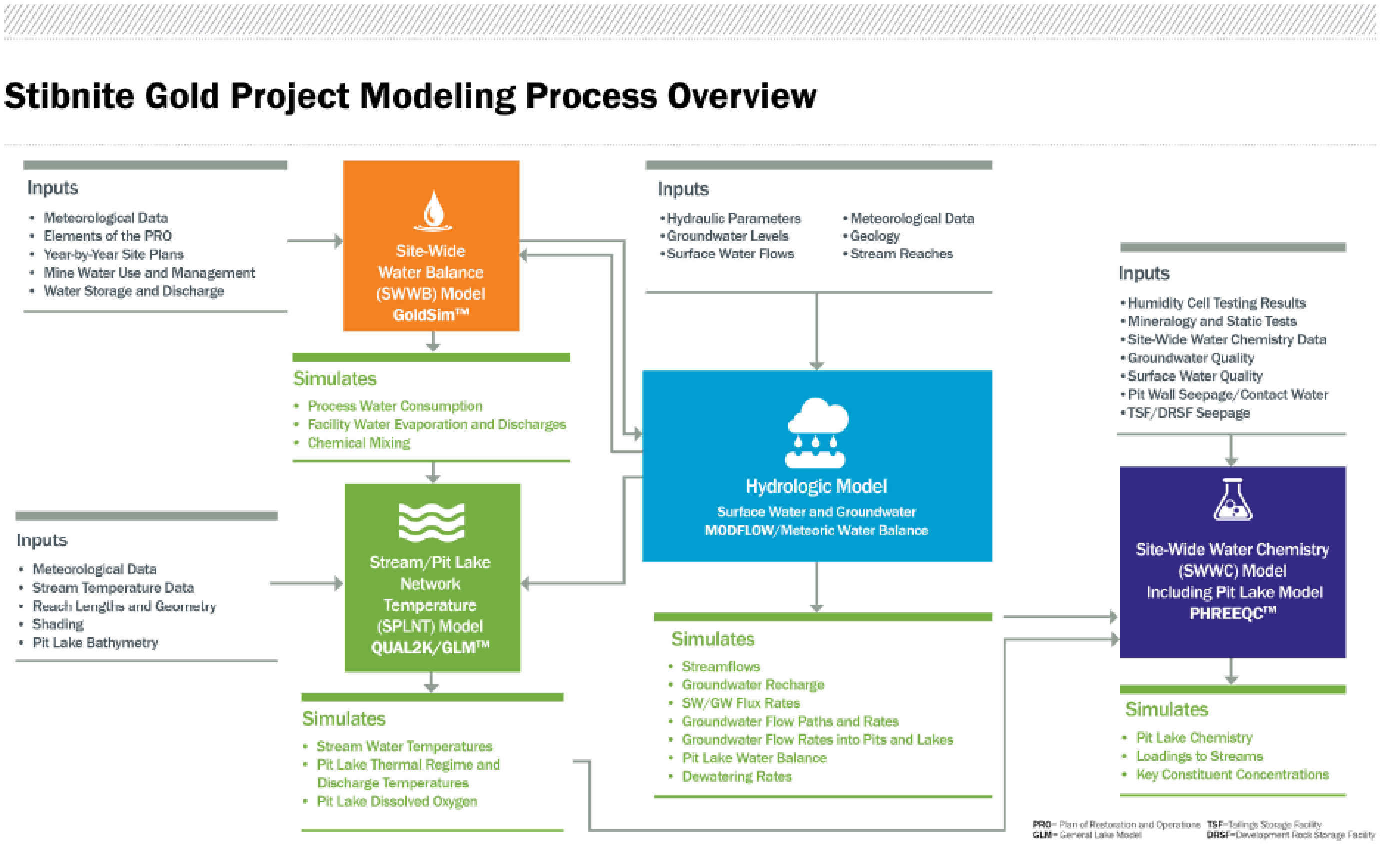


Figure 1. SGP Modeling Process and Analysis Tools (B&C, 2018 Existing Conditions Study)

# 4 Specific Findings

## 4.1 Issues with Overall Methodology Used to Evaluate Impacts

Understanding the current hydrologic flow system and predicted changes due to mining rely heavily on modeling tools that involve successfully completing a number of sequential steps to produce realistic and reliable results that overseeing agencies use to make informed decisions. Problems encountered at any of these steps propagate through subsequent steps, and degrade end results, or simulation of existing conditions, and predicted changes due to mining.

A general ‘industry-standard’ approach for developing and applying appropriate models to assess hydrologic impacts is lacking in the DEIS, despite B&C presenting a general flow chart (Figure 1) showing how model inputs and outputs are shared across all tools used to assess existing and mine-impacted conditions. A general modeling approach used to develop predictions via use of numerical models was never presented. For my assessment, I reviewed all relevant hydro-related DEIS documents for deficiencies/problems following various modeling steps following the industry standard modeling approach provided by Wels, 2012[6] (see Figure 2**Error! Reference source not found.**).

Clearly defined questions related to potential impacts and modeling objectives should have been presented, particularly how groundwater impacts affect surface flows, and vice-versa. These were not evaluated in this DEIS, or supporting documents. Findings are organized by the following standard modeling steps:

- Were modeling objectives clearly defined? (Section 4.2)
- Is data adequate for the DEIS? (Section 4.3)
- Is the interpretation, or characterization of data adequate for the DEIS? (Section 4.4)
- Are conceptual flow models adequately defined/defensible? (Section 4.5)
- Were appropriate codes selected to support analysis of existing conditions and future mine impacts? (Section 4.6)
- Were model input setup/assumptions appropriate? (Section 4.7)
- Were Calibration/Sensitivity analysis adequate? (Section 4.8)
- Were Predictive Scenarios simulations adequate, including uncertainty analysis? (Section 4.9)

## 4.2 Modeling Objectives Don’t Focus on Environmental Impacts

Though the DEIS Section 4.8.1 presents ‘Effects Analysis Indicators’, and DEIS Sections 4.8.1.1.1 and 4.8.1.1.2 present ‘primary objectives’ such as simulation of surface water-

---

[6] Wels, C. and Mackie, D., Scibek, J. 2012. Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Activities, British Columbia Ministry of Environment, Water Protection & Sustainability Branch, Report No. 194001.

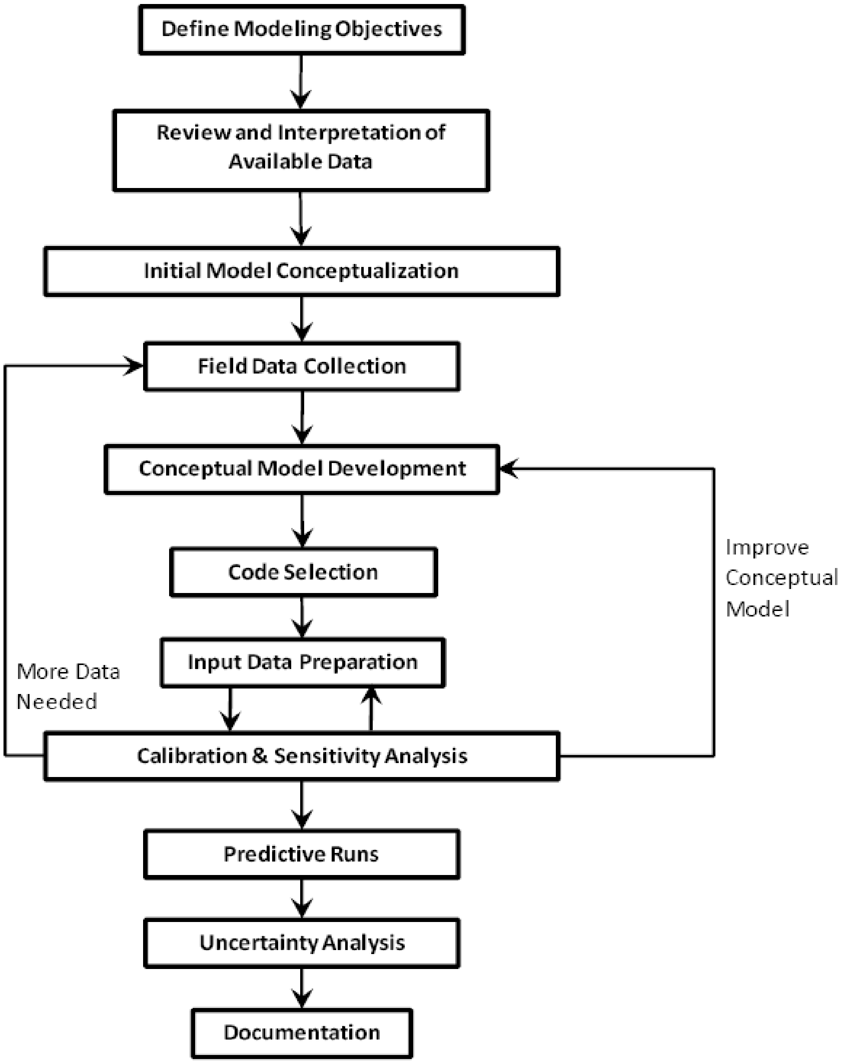


**Figure 3-1: Modelling as a multi-phase, iterative process.**

Figure 2. Proposed Groundwater Modeling Process (Wels, 2012)

groundwater flows and groundwater elevations/flow (and changes to these due to mining), these don't describe higher-level objectives required to develop hydrologic models that focus on meeting fundamental needs of the EIS, such as fully understanding existing and mine-impacted system surface water and subsurface hydrologic system and its controls/influence on Groundwater Dependent Ecosystems (GDEs), wetlands/riparian, vegetation, fish/habitat, and wildlife. Defining objectives in this way would have focused attention on selecting more appropriate modeling tools, required level of calibration target accuracy, prioritized calibration areas (i.e., GDEs, wetlands etc), and specifying appropriate input data to meet EIS needs.

## 4.3 Field Data Inadequate for DEIS

A number of basic, essential datasets are unavailable, or highly spatially-biased and only available in the immediate area of proposed mining, but importantly are absent in areas impacted by the mining. This is a critical oversight in the DEIS[6].

This doesn't mean that data has to be collected everywhere at a high spatial density. However, data should have been collected in key locations that affect modeling baseline conditions to demonstrate full understanding of hydrologic behavior and controls. Modeling methodology does exist to deal with limited datasets, but inevitably this requires developing more conceptual flow models to account for increased uncertainty about for example, hydrogeologic framework/property distributions. In the end, this results in increased predictive uncertainty, which if too great, can only be reduced by collecting more data to confirm one conceptualization over others.

Key data gaps identified include:

- In general, subsurface geologic and hydraulic data are largely missing outside the immediate Meadow Creek/EFSFSR mainstem drainages. This greatly increases the overall uncertainty of the conceptual flow model over the domain described in the existing conditions modeling analysis.

- Mapping of Alluvium/Colluvium throughout model domain lacking

- GDEs were mapped over entire extent of the model domain – but surface water/groundwater hydrologic data are missing.

Wels et al, 2012[6] states on Page 58, P6 "*If critical data gaps are identified, these gaps need to be filled by additional field work before the conceptual model can be completed and the modelling study can proceed. In some cases such additional field work can be avoided (or at least postponed) by: (i) using two alternative conceptual models that cover the uncertainty due to the data gap; and/or (ii) using conservative assumptions in the conceptual model.*" B&C 2018 failed to discuss major gaps in field data (i.e., all non-stream areas), and should have either created additional conceptual models through predictions, or clearly defined conservative conceptual assumptions (where conservative means making assumptions on inputs that result in larger impacts.

### 4.3.1 Groundwater Well Distribution Spatially Biased

For such an important calibration dataset to developing an accurate and reliable model, used as the primary tool for predicting impacts of the proposed mining and post-closure effects, DEIS reports are unclear and inconsistent regarding a) which wells are used to guide calibration, and b) why a number of wells within the West End Pit were not included in the analysis. For example:

- The B&C 2017 SGP Water Resources Summary study indicates (Page 809, P1) that a total of 66 wells, 48 alluvial and 15 bedrock and 3 multilevel wells exist in the study area.
- However, the B&C 2018 Existing Conditions report reports only 50 wells (Table 2-1), but in Table 5-1 show calibration statistics for 55 wells, 35 in the overburden, and 20 in bedrock.
- The John Shomaker & Assoc, Inc, 2017 Final Workplan: Hydrologic Model of the Upper Watershed of the East Fork of the South Fork of the Salmon River, Stibnite, Idaho shows 91 wells (see Figure 2.17 and Table 2.5), a number of which occur in the West End Pit area. Surprisingly, the B&C 2018 Existing Conditions modeling study failed to include an of the West End Pit wells,

None of these wells is outside the main Meadow Creek and EFSFSR valley alluvium area. So in effect, the available wells are highly spatially biased. The lack of wells outside of these local valley areas (i.e., hillslope and hilltop areas) precludes monitoring/understanding/characterizing how the groundwater system flows in all the surrounding areas that feed into the valley. This introduces considerable uncertainty/non-uniqueness in the modeling.

### 4.3.2 Soil data across the entire model area lacking

Available soil data is focused around the immediate area of the mine, yet absent over the majority of the hydrologic model area. Associated soil hydraulic data are essential input for realistically calculating recharge, runoff and evapotranspiration across the entire model domain. None of these data were used in the B&C 2018 EC modeling, though the MIKESHE model does make assumptions about average soil types/hydraulic properties across the model area, consistent with Section 2.4 soil types summarized in 2017 Midas Gold Gelogy and Soil Resources Supplemental Baseline Study.

### 4.3.3 Hydraulic Testing Information Lacking

Existing conditions report effectively relies on only one, localized 30-day test, further limited to local-area influence because response further from the Gestrin well encountered a boundary. These sorts of features should have been included in the existing conditions model, and discussed at length, especially where they may influence predicted mine impacts during/post-closure.

### 4.3.4 Climate Data Relies on Reginal Data Instead of Local Data

These data are essential to assessing existing/historical hydrologic conditions for both surface and subsurface flow systems.

Precipitation data. A local climate station at Stibnite is available but doesn't appear to correlate well against PRISM dataset nor does it appear to have been used as input in the hydrologic modeling. Instead, long-term monthly PRISM data were used as local station data don't exist prior to ~2011. The PRISM dataset, though commonly relied on where data are missing, are estimated from surrounding station data, and using various algorithms to correct for elevation effects/storm types etc). The DEIS should have required local climate data at different elevations around the modelled watersheds, given the notable variation in average annual precipitation.

## 4.4 Hydrologic Characterization Lacking/Poor

A number datasets weren’t characterized well in the DEIS documents, including:

a) Inadequate hydraulic testing across the entire proposed mine footprint, and also within the entire hydrologic model area are lacking. One implication is that aquifer storage values are likely too low by 1-2 orders of magnitude (as confirmed by comparison of MSHE simulated transient heads to observed with modified values). Storage values should have been better characterized, and consistent with geologic modeling of the system.

b) Geologic characterization over the extent of the entire hydrologic model is lacking.

    a) Why wasn’t a geologic model of model area developed to facilitate development of the groundwater flow model? This is mining industry standard practice and generally always presented in mining DEIS supporting documentation.

        a. Many geologic boreholes were provided in the 2017 B&C Water Resource Summary report, but weren’t used to refine the groundwater flow model. Instead the flow model specifies uniform/overly-simplistic hydraulic properties for all alluvium, and bedrock zones throughout the model. They omitted known faults, fault/fracture zones, fault offsets and variations in overburden (i.e., glacial deposits versus alluvium).

        b. Clearly many boreholes exist through all of the proposed ore deposits – but these weren’t used to refine the model inputs either.

    b) Bedrock fractures 500’ not realistic/justified with data – and MSHE shows it isn’t needed. W/higher WZ K, and low non-fractured rock 500’.

c) Hydraulic characterization of the proposed Rapid Infiltration Basin (RIB) area is missing,which would have required specific wells in this area, and hydraulic testing to confirm the range of infiltration capacity/response. This directly affects the water management plan.

d) Though the 2017 B&C Water Resources Summary report presents some characterization of stream losing/gaining stretches, which represent valuable calibration constraints, they fail to characterize losing/gaining response throughout the year and over a broader extent (i.e., B&C hydrologic model extent).

e) Climate data distributions over model area

    a. Precipitation data apparently NOT spatially distributed, yet clear evidence exists (from prism dataset – 800 m resolution) that it increases with elevation.

    b. A magical scaling factor is referenced, which increases the local station data (or PRISM data) by more than 20%.

c. Snow is critical to driving much of system hydrologic behavior/response. Yet snow course data appears unavailable within the catchment. Instead snow course data (or Snow Water Equivalent – SWE) data are estimated from stations (many miles away). MIKESHE modeling below indicates through calibration against HOURLY transient head and discharge data over years – that SWE varies substantially throughout domain based on elevation, and importantly melts out at different rates, which strongly control spring freshet flows/peaks/timing/volumes etc.

f) Groundwater Dependent Ecosystems (GDEs), or Seeps, springs and wetlands are important ecological indicators that should have been much better characterized:

   a. Better assessment and hydraulic testing of GDEs likely directly affected by proposed mining/operations should have been performed,

   b. GDE discharge should have been monitored continuously throughout the year to better understand how these features would be impacted by mining.

### 4.4.1 Identification and Hydraulic Characterization of Faults Lacking.

Table 5-2 (Page 5-9, B&C Water Resources Summary 2017) summarizes details about the more prominent faults in the mine area. Stewart et al, 2016 show many other faults mapped within the extent of their study, which only extends over part of the modelled area. Figure 5-2 in B&C Water Resources Summary 2017 report also presents this information. Despite the acknowledgement of faulting throughout the model domain, and most historical mining associated with the fairly well defined extent/nature of the Meadow Creek fault zone, no hydraulic testing was conducted, or presented in the DEIS or supporting documents, to assess the hydraulic characteristics associated with faulting in the area (i.e., do faults impede flows, or enhance flows along them?). This is a critical oversight in the DEIS, because if faults:

1) Impede flow – they would tend to compartmentalize groundwater flows, which could:
   - Limit the extent of dewatering in the groundwater system
   - Limit the amount of dewatering water extracted
   - Directly affects the nature of impacts of dewatering on streamflow,
   - Directly affects the amount of water managed
2) Enhance flow – would likely:
   - Increase the nature/magnitude/extent of pit dewatering
   - Increase the predicted dewatering rates, dewatering times,
   - Increase the amount of water to manage
   - Change the pitlake flow through and stream temperature calculations

### 4.4.2 Influence of Historical Mining Features on Hydrologic Flow Conditions

The Plan of Restoration and Operation – Appendix D (2016 SGP Plan of Restoration and Operations, page D-8) shows a cross-section (Figure 2) on Figure 3. This figure indicates substantial underground workings and interconnected tunnels extending from higher elevation

Hangar Flats (south) to Yellow Pine Pit and eventually into Sugar Creek via Bailey Tunnel (north). None of the modeling studies reviewed appeared to account for likely continued mine groundwater drainage into the EFSFSR drainage via Bailey tunnel through gravity drainage. It's unclear whether existing conditions modeling, or proposed action/alternative configurations took these important drainage features into account.

The Water Resources Summary Report[7] on page 8-7, P8 states "*Lastly, historical mine workings such as adits may discharge to Quaternary aquifers.*", though this wasn't considered, or evaluated as a conceptual flow model alternative in the existing conditions modeling study.

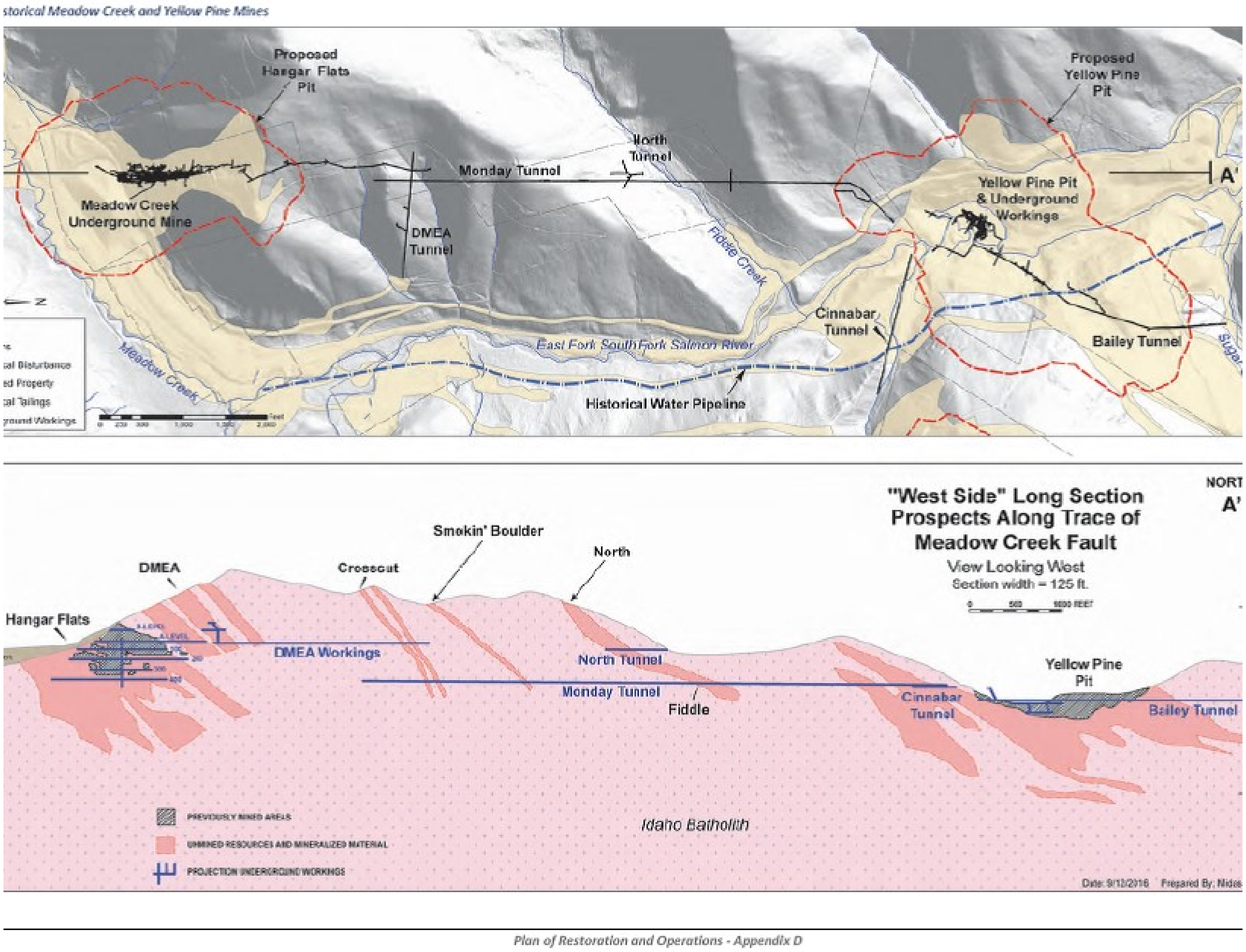


Figure 3. Figure 2 from App D in 2016 SGP Plan of Restoration and Operations, page D-8.

## 4.5 Conceptualization inadequate/incomplete.

Conceptualization is critical to supporting and developing numerical models of flow as described in numerous modeling guidelines[6]. Kolm and Van Der Heijde, 1996[8] describe a detailed approach

---

[7] Brown and Caldwell 2017 Stibnite Gold Project, Water Resources Summary Report. Prepared for Midas Gold Idaho, Inc. June 30.

[8] Kolm, K.E., Van Der Heijde, P., 1996. Conceptualization and characterization of envirochemical systems. Calibration and Reliability in Groundwater Modelling (Proceedings of the Model CARE 96 Conference

to conceptualization and characterization of hydrologic systems, as outlined on Figure 5.

The B&C 2018 EC modeling study fails to present and describe a defensible 3-dimensional conceptual flow model, though the B&C 2017 Water Resources Summary report does present a 2-dimensional conceptual hydrogeologic cross-section (Figure 4). However, it is standard practice in developing groundwater flow models to develop multiple conceptual flow models to account for uncertainties in model setup/parameterization[9]. And though B&C Figure 9-1 (Figure 4) does include important flow arrows, various components of this conceptualization are not reflected in the Existing Conditions flow model (B&C 2018).

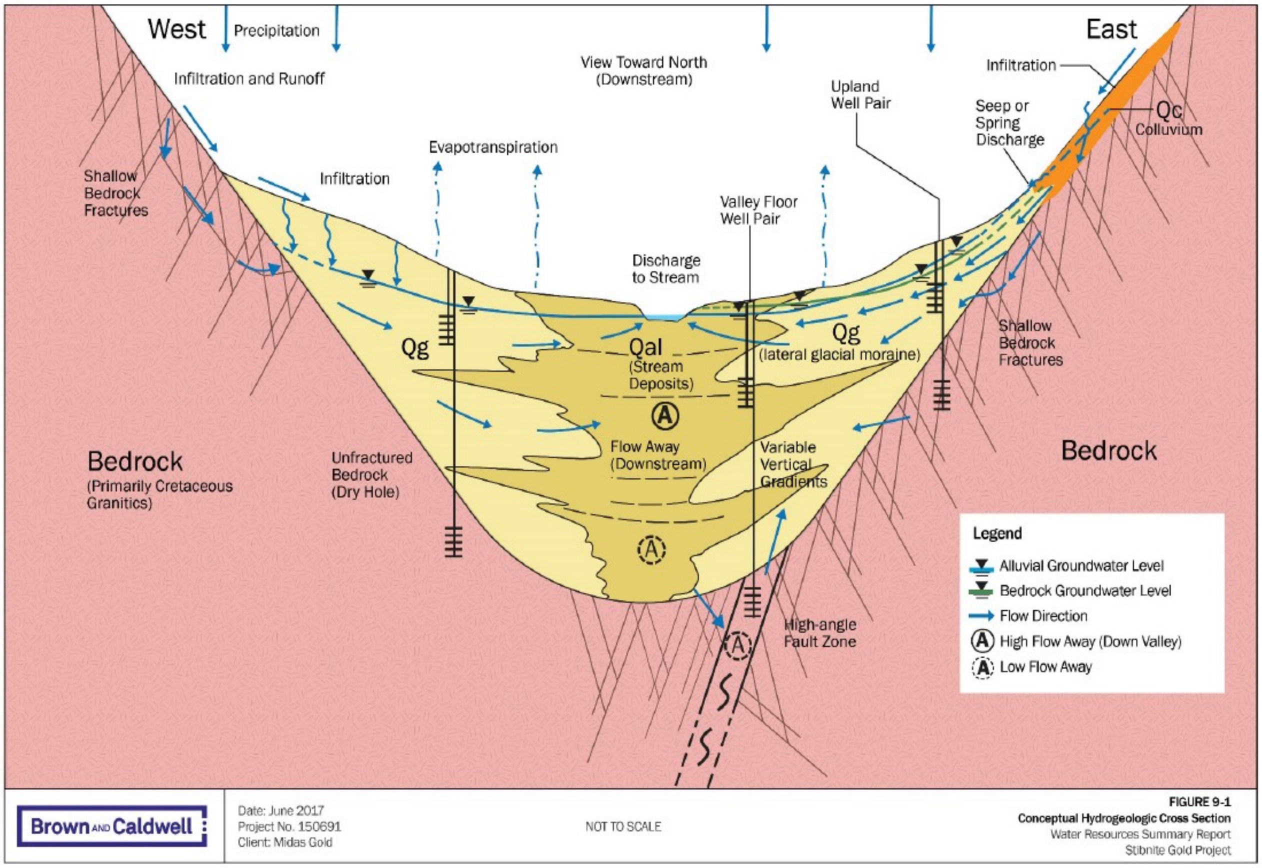


Figure 9-1. Conceptual hydrogeologic cross section

Figure 4. Figure 9-1 from B&C 2017 SGP Water Resources Summary report.

For example:

- the EC model doesn't attempt to simulate any of the seeps/springs, or even consider mechanisms for simulating such important features (i.e., impacted GDEs) and how they may be affected by mining (i.e., they could be attributed to fault/fracture discharge to surface, geologic contacts, overburden material type transitions etc).

---

held at Golden, Colorado, September 1996). IAHS Publ. no. 237, 1996.

- Another example is that upland areas shown on the conceptual 2D section show shallow bedrock fractures, yet the EC model assumes that bedrock is fractured (and therefore more permeable) only beneath all streams, and arbitrarily assumed to be 500 ft thick.
- Within the thicker valley fill areas (i.e., Meadow Creek near Hangar Flats), even surficial geologic mapping shows Qal stream alluvium embedded within broader Glacial Deposits (Qg), where Qal exhibits greater silts, or lower permeabilities (at least vertically). Yet the EC model lumps the entire 'overburden' into a single layer. Further, the EC model fails to consider hydraulic property variations, such as between Qc (colluvium) and adjacent Qg materials, where their conceptualization shows seeps/springs occur.

When underlying conceptual flow models show such inconsistencies across the modelled domain, subsequent numerical flow models suffer the same flaws. These flaws manifest themselves in both the EC modeling, but more importantly translate into all subsequent predictive models. As a result, things like predicted drawdowns around pits, dewatering rates, drawdown/discharge impacts to surrounding GDEs, streamflow and RIB infiltration are all subject to such errors/predictive uncertainty.

Figure 4 (Figure 9-1 from B&C 2017 SGP Water Resources Summary report, page 9-3) indicates the flow conceptualization exhibits some flaws:

- Soils likely exist in almost all areas – proof is that vegetation occurs in most all areas of model. The soils in all areas are likely at least 1 meter thick, to support vegetation root structures. These hillslope soils are important component to conceptual hillslope models, and strongly govern recharge vs runoff allocation and dynamics, and additionally play an important dynamic role in AET dynamics and total water balance/recharge dynamics etc.
- B&C 2018 EC report → suggests high permeability zone occurs in fractures below valley sediment only, yet this conceptualization shows fractures all the way up hillslopes?
- Why is ET only shown in valley sediment? It also occurs on hillslopes and is not insignificant.
- Given the high degree of complexity in the subsurface over the mine footprint, a realistic range of alternative conceptual models should have been considered in the modeling to account for substantial uncertainty in virtually all model input. Conceptual model uncertainty typically accounts for most uncertainty in subsequent numerical model predictions. Neuman and Weiranga, 2003[9] describe in detail how to incorporate alternative conceptual models into formal uncertainty analyses. Typically, conceptual model uncertainty dominates overall predictive uncertainty and as such should have been more fully assessed in the DEIS modeling evaluations.

---

[9] Neuman, S.P., and Weiranga, P.J. 2003. A Comprehensive Strategy of Hydrogeologic Modeling and Uncertainty Analysis for Nuclear Facilities and Sites (NUREG/CR-6805).

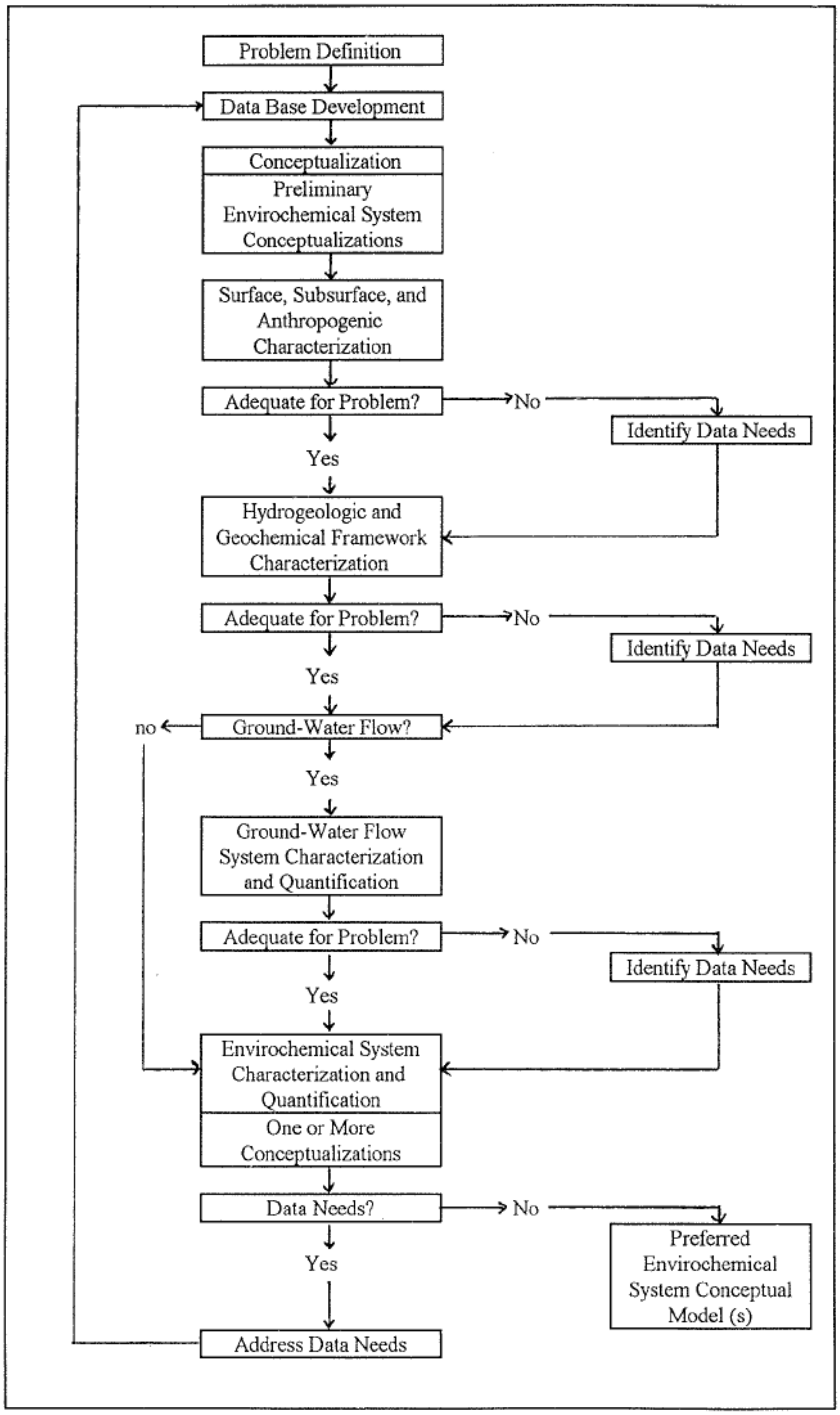


**Fig. 1** Procedure for conceptualization and characterization of envirochemical systems.

Figure 5. Hydrologic Characterization and Conceptualization Approach, Kolm and Van der Heijde, 1996.

## 4.6 Issues with Hydrologic Codes Used to Evaluate Impacts

To estimate the impacts of proposed mining, MG used several tools, including:

- Hydrologic Model - MODFLOW-NWT coupled to external Spreadsheet-based 'Meteoric Water Balance' Tool
- Site Wide Water Balance Model (SWWB) – using the Goldsim software
- Stream/Pit Lake Network Temperature Model – using the Steady State Surface Water Code Qual2k

Where is discussion of DEIS objectives related to environmental impacts – and necessary tools??

### 4.6.1 No Formal Code Selection Process

A formal code selection process[10] should have been conducted to identify appropriate codes that are able to simulate all required processes needed to fully assess mine impacts on surrounding hydrology, and more importantly, to define required calibration targets for specific EIS impact assessments (i.e,. required predictive accuracy). Section 5 in Wels, 2012[6] provides details on conducting a formal groundwater model selection, even including a flow chart. Industry standard ASTM standards, developed used for decades, describe in detail how codes should be selected, starting with defining all of the needs (i.e., DEIS related needs – not mining needs), objectives, complexities and desired outputs.

The MODFLOW-NWT groundwater modeling tool described in the B&C 2018 Existing Conditions Study to assess mining impacts at GDEs within the entire mine footprint fails to model important physical processes (i.e., overland surface runoff processes, distributed recharge and evapotranspiration dynamics, stream hydrodynamics, and stream-aquifer dynamics etc.) necessary to simulate physically realistic and defensible mine impacts on surrounding GDEs. Much more robust modeling software codes are readily available, but weren't considered because a formal, industry standard code selection process wasn't conducted, where all modeling objectives/needs are carefully defined and evaluated against capabilities of available codes.

Fully integrated hydrologic/hydraulic codes should have been considered for more robust and physically realistic impact evaluation. These codes don't suffer major shortcomings such as: 1) attempting to run one model in isolation (i.e., the groundwater flow model), then attempting to couple non-dynamic results to a separate spreadsheet tool, when the flows between groundwater and surface water is complex, dynamic and spatially variable, and 2) they simulate all relevant physical flow processes and don't require unrealistic and highly uncertain boundary conditions. Many options are commercially-available[11] and have been applied to mine water balance projects, worldwide for many years.

---

[10] Technical Guide to Ground-Water Model Selection at Sites Contaminated with Radioactive Substances, EPA 402-R-94-012, September 1994. NTIS, PB94-205804/XAB.

[11] AquaResource Inc. 2011. "Integrated Surface and Groundwater Model Review and Technical Guide." For The Ontario Ministry of Natural Resources.

1) Use of Modflow to explicitly model the effect of faults is inappropriate. Codes like FEFLOW permit actual simulation of flow along faults as planar features. Modflow-Surfact required specifying model cells (with variable dimensions unrelated to actual fault planes/zones in the field). Hydrogeologic characterization of flows along and/or across faults is largely missing – and therefore highly uncertain.

2) The variable saturation, finite element modeling code, FEFLOW, developed by DHI-WASY would have allowed a much higher resolution near critical streams, while decreasing resolution in area of less interest. This would have met stated objectives.

3) Fully integrated, or coupled, physically-based, fully-distributed hydrologic (and hydraulic) codes have been available for decades and would have allowed MG consultants to directly simulate the complicated, baseline and mine-impacted coupled surface water-groundwater dynamic flow system response in a much more robust, realistic way.

   The authors attempted to estimate spatial distributions of recharge, which is a complex spatially distributed, and dynamic process, using an undocumented method. However, fully integrated codes like the USGS GSFLOW code, DHI's code MIKESHE/MIKE11 or even Aquanty's Hydrogeosphere code actually simulate important processes like dynamic, spatially-distributed recharge, surface runoff and channelized hydrodynamics, which are dynamically coupled to subsurface flow (i.e., coupled to a modflow equivalent code). The MIKESHE code was used to simulate hourly impacts of climate change and stream temperature changes associated with Pebble Mine impacts in southeastern Alaska[12].

### 4.6.2 External Spreadsheet Water Balance Tool Inappropriate

The Spreadsheet Meteoric Water Balance tool is inappropriate for simulating complex, spatially/temporally distributed hydrologic processes not simulated with the Modflow model for a variety of reasons:

1. The Meteoric water balance equation appears physically incorrect, doesn't appear to be based on any well-established published methodology, and is only vaguely described in the calculation of primary water balance components.
2. Calculation of several monthly hydrologic process flows is physically incorrect:
   a. **Potential Evapotranspiration** (a maximum rate of loss to the atmosphere) is calculated using an overly simplistic method (Thornwaite) and further defined based on some function of elevation (methodology and associated parameters not provided) and reduced if higher than 'available' snowmelt + rainfall to zero. This is physically incorrect and unrealistic for several reasons, and important because evapotranspiration is the second largest water balance component in the watershed, behind precipitation:

---

[12] Wobus C, Prucha R, Albert D, Woll C, Loinaz M, Jones R (2015) Hydrologic Alterations from Climate Change Inform Assessment of Ecological Risk to Pacific Salmon in Bristol Bay, Alaska. PLoS ONE 10(12): e0143905. https://doi.org/10.1371/journal.pone.0143905

    i. It is industry standard to calculate much more robust estimates of PET (actually now referred to as Reference ET based on specific reference crops) using well accepted/established methods like the FAO Penman-Monteith (PM), or ASCE PM methods[13] that depend on more local meteorological factors than just average daily Temperature (for the month), such as hourly relative humidity, net Radiation (including effects of clouds), soil heat flux, wind speed, air temperature and precipitation.

    ii. The B&C 2018 EC modelers confused PET with Actual Evapotranspiration (AET), where AET is what the hydrologic system actually uses, and PET is the potential or maximum possible amount used, if vegetation are well watered and similar to the reference crops used to calculate the PET (i.e., typically either grass or alfalfa). The MIKESHE model, utilizing a Penman-Monteith PET timeseries, calculates that AET for the entire model watershed area ranges from 43% to 90% of PET, from years 2011 through 2018. **This is a notable error in the meteoric water balance, which changes the entire subsequent water balance estimates of recharge and runoff.**

    iii. While the AET can be expected to vary as a function of elevation, it is physically unrealistic and unjustified (i.e., present a published methodology to justify this) to then reduce PET to available rainfall + snowmelt (so that PET is not > rain and snow), which does not consider the availability of water in the rootzone and groundwater. In otherwords, it is well known in hydrology for example in arid zones, that PET is often much greater than rainfall + snowmelt at a monthly or yearly timestep.

b. **Recharge/Runoff Calculation Incorrect:** In reality, the subsequent physical movement of precipitation as rain or snow, once available at the groundsurface is not simply first allocated to maximum possible recharge, then to runoff, all at a monthly timestep for several reasons:

    i. Recharge dynamics are strongly coupled to AET dynamics and runoff, but at an event-level timestep (i.e., minutes to hours), not monthly. All of these processes are much more complex and depend on many more factors than described in the meteoric water balance.

    ii. No methodology is presented on exactly how B&C estimate recharge, based on 'assumed hydraulic properties of the surface material' (page 3-2, 2018 B&C 2018 EC model study). See Section 4.7.4.1 for further explanation of this critical model input.

    iii. No methodology or physical basis is presented for allocating remaining 'available water' to surface runoff, which then dominates the entire calibration of surface flows in the MODFLOW SFR package, but is physically unrealistic.

---

[13] Allen, R.G., Pereira, L., Raes, D., Smith, M., 1998. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. FAO - Food and Agriculture Organization of the United Nations Rome, 1998

> The MIKESHE model predicts that the ratio of baseflow to runoff lateral inflow to rivers within the model area average ~150% and range from 82% to nearly 240% from 2011 through 2018. This indicates that groundwater discharge (or recharge) produces much more of the river flow than runoff, yet the B&C model estimates an average ratio of recharge/runoff of ~19% for hillslopes

### 4.6.3 Modflow Streamflow Simulation Problematic

The B&C 2018 existing conditions modeling utilizes the "Modflow SFR" (page 4-3, P2) package, but failed to indicate whether this was the SFR1[14] or SFR2 package[15]. If the SFR2 package was used, the B&C 2018 report fails to present input data/assumptions associated with unsaturated zone beneath simulated streams. If the SFR1 package was used, the documentation says "*The Package is not recommended for modeling the transient exchange of water between streams and aquifers when the objective is to examine short-term (minutes to days) effects caused by rapidly changing streamflows.*". The selected modeling tool is therefore incapable of important simulating stream-aquifer interaction dynamics at an event-level, which is problematic as the surface discharge hydrographs at gages throughout the mine clearly show a high level of sub-monthly dynamics, particularly in response to spring freshets. **As a result, the selected hydrologic modeling tools used in the DEIS can't assess mining impacts to wetlands, vegetation, fish, habitat, wildlife etc that heavily depend on event-level dynamics (i.e., hours to days), where substantial variations in stream flows, velocities, stage, water quality, stream temperature etc occur.** Furthermore, **t**his also doesn't account for additional setup issues identified in Section 4.7.5.

## 4.7 Model Setup/Assumptions Flawed.

A number of issues were identified with the setup of the groundwater flow and TSF seepage flow models that severely limit confidence in a realistic range of mine impacts on the surrounding hydrologic system, including water quality impacts.

CRITICAL to get existing conditions right. All other modelled predictions depend on this directly! All flaws/errors/uncertainty are translated into other models/predictions!

a. Assumed monthly hydrologic timestep presumed adequate, but is inadequate for DEIS (see Section 4.7.1)

b. Meteoric Water Balance calculations are incorrect and physically unrealistic (see Section 4.7.2)

---

[14] Prudic, D.E., Konikow, L.F., and Banta, E.R., 2004, A new streamflow-routing (SFR1) package to simulate stream-aquifer interaction with MODFLOW-2000: U.S. Geological Survey Open-File Report 2004-1042, p. 95.

[15] Niswonger, R.G., and Prudic, D.E., 2005, Documentation of the Streamflow-Routing (SFR2) Package to include unsaturated flow beneath streams—A modification to SFR1: U.S. Geological Survey Techniques and Methods 6-A13, 50 p.

c. Spatial distribution and magnitudes of hydraulic property specifications are unrealistic and unjustified with actual data/testing (see Section 4.7.3)

d. Physically incorrect/unrealistic calculation of recharge and runoff (see Section 4.7.4)

e. Unclear/incorrect setup of MODFLOW Stream Flow Package SFR (see Section 4.7.5)

f. GDE seepage and spring flow not simulated (see Section 4.7.6)

g. Modeling of Evapotranspiration is Incorrect (see Section 4.7.7)

### 4.7.1 Monthly Timestep of Hydrologic Model Doesn't Meet Needs of DEIS

The B&C 2018 EC modeling study, Section 4.1, Paragraph 1 states "*Monthly stress periods are considered adequate to capture changes in groundwater flow conditions and stream baseflows in response to long-term changes in recharge and surface runoff*." Despite the suggestion by B&C here that a monthly stress-period (or time-step) is adequate, this assumption represents a significant flaw in the entire hydrologic modeling analysis, which should have required assessing hydrologic impacts of mining at a much finer resolution to meet critical needs of the DEIS. Major reasons this is a major flaw includes:

1) The physical processes that dictate groundwater, surface water and evapotranspiration hydrologic processes are strongly dominated by atmospheric boundary conditions, which occur at the sub-hourly to daily range (i.e., most storms last this long). Even snowmelt dynamics, as reflected in nearby SNOTEL snow course data strongly indicate these snowmelt dynamics occur rapidly, over days to weeks, rather than monthly. As a result of assuming monthly timesteps for ALL hydrologic modeling (i.e., existing conditions, but also all subsequent predictive modeling), MG consultants are unable to assess sub-monthly impacts of mining on the hydrologic system. This has important implications in not being able to assess how mine features/designs and operations during and following closure affect, for example:
    a. How does the hydrologic system respond to large storm events?
        i. Do some mine areas flood?
        ii. What is the potential for failures?
        iii. How do extreme short-term hydrologic responses affect designs? Operations?
        iv. Water management plans?
        v. What is the potential impact on erosion, suspended sediment, sediment transport, deposition? What are impacts of event-level high TSS/TDS on the ecosystem/fish/vegetation?
    b. How does the hydrologic system respond to drought conditions?
        i. Are there sub-monthly periods of zero/low flows that affect the quality of wetlands/fish habitat?
    c. How do extreme wet/dry periods affect stream temperatures?

2) The monthly timestep was selected here out of convenience rather than based on actual DEIS needs.

    h. The underlying PRISM climate data used to estimate ‘available water’ was only available at a monthly timestep.

    i. Site weather data were not used in the hydrologic modeling – but should have been collected at multiple sites within the catchment, given the strong orographic effects on total precipitation,

    j. Monthly timesteps are much easier to calibrate – because individual storm hyetographs and resulting hydrologic responses at a sub-monthly period don’t have to be calibrated, and effectively get lumped into average monthly estimated flows.

3) The B&C 2018 EC model calibration period was selected from 1985 through 2016 (Section 4.1, P1), though review of actual MODFLOW model setup information suggests this period extended to 2018. No supporting rationale was provided to support including this period of calibration, particularly because available groundwater head data don’t appear available prior to 2011. If the calibration period prior to 2011 was included solely to calibrate against monthly surface flows, this makes the calibration solution during this period even more non-unique, or uncertain. A much better and relevant approach for the DEIS would have been to run and calibrate the model to at least daily fluctuations.

### 4.7.2 Meteoric Water Balance is incorrect and physically unrealistic

See Section 4.6.2 for various reasons the Meteoric Water Balance Spreadsheet method is incorrect, physically unrealistic and no published methodology presented.

**Importantly → these water balance flaws and non-physical basis at monthly timesteps make it impossible to correctly predict hydrologic changes due to mining (i.e., recharge, runoff and AET) without using realistic, well-accepted physical equations AND hydraulic properties associated with the mine modifications (i.e., TSFs, DRSFs, streambed reconfigurations, revegetation, revised soil layering and slopes, pits etc).**

### 4.7.3 Specification of Subsurface Layers and Hydraulic Properties Unrealistic and Unsupported by Field Data or Characterization.

A number of issues were identified with how hydraulic properties were specified in the the B&C 2018 EC model, including:

- Layer 1 – Alluvium/Colluvium Thickness poorly defined/justified.
    - EC study (Figure 2-5) indicates variable (<50’) overburden thickness outside of localized Meadow Creek/EFSFSR main drainage, but fails to estimate thickness based on data for all other areas modelled outside of interpolated overburden thickness. No basis for the interpolation is provided (i.e., borehole control points) for the interpolation, and variable thickness outside of known well locations appears random. If this is an unknown property

  over most of the model – this by itself would warrant need for multiple conceptual flow models to account for this important source of model uncertainty. **By not considering this uncertainty, all predictions of existing flow conditions and all mine impacts are considered highly uncertain.**

  - Hydraulic properties for 'Upland Overburden' are unrealistic and unjustified. The MIKESHE model shows that upland overburden horizontal and vertical conductivity values are 1 to 2 orders of magnitude higher than specified in the B&C 2018 EC model.
  - Recent detailed geologic mapping of the Stibnite Quadrangle by Stewart et al 2016[16] indicates drainages largely consiste of Glacial Deposits (Qg), consisting of unsorted to poorly sorted cobbles, gravel, boulders, and sand. Within the lower valleys (i.e., in Meadow Creek, where tailings exist), Alluvium consists of higher percent silts. As a result – Layer 1 should have simulated thicker/more extensive Sedimentary Deposits of mostly glacial deposits.
  - The distribution of colluvium/alluvium by B&C 2018 existing conditions modeming study → is inconsistent with detailed surficial geologic mapping by Stewart et al, 2016. Importantly, within Meadow Creek, where the proposed TSF/DRSF is proposed, B&C appears to have mapped much less Qg than exists.

- Layer 2 – Fractured/Un-fractured Bedrock. The preliminary MIKESHE model simulations suggested addition of a 10 m thick, isotropic, relatively high conductivity layer, immediately underlying the alluvium (i.e., 100 ft/day). The specification of a 500' thick, higher conductivity zone beneath ALL streams to represent a fractured bedrock zone is unrealistic and unsupported by any data/testing.
- Faults as either impediments to flow, or enhancements to flow along them were not considered, yet multiple faults have been mapped through the mined/surrounding area and even interpreted as compartmentalizing groundwater flow conditions. **Not incorporating faults into the conceptual flow model and parameterization of the subsurface is a major deficiency in the DEIS analysis of mine impacts.** The MODFLOW-NWT code used in the DEIS analysis easily incorporates faulting, and it is industry standard practice to include the effects of faulting both in calibration and predictive simulations to assess impacts of proposed mining on surrounding hydrology. The MIKESHE model (see Section 5) actually incorporates faulting as lower permeability features along faults mapped (yellow lines) on Figure 7, in the second conceptual model evaluated, which yields good calibration against transient heads and streamflow. Even the sensitivity evaluation failed to include these, which other major DEIS evaluations have included.
- Section 4.2.1.3 in the SPF 2017 Groundwater Hydrology Baseline study indicates that results of the 31-day hydraulic aquifer test at the Airstrip Well, resulted in specifying a high fractured rock hydraulic conductivity value of 400 feet/day in the surrounding area (i.e., the Gestrin Feature), while the same area in the B&C 2018 EC modeling study specified a value of 7.5

---

[16] Stewart, D.E., Stewart, E.D., Lewis, R.S., and Weppner, K.N., 2016, Geologic map of the Stibnite quadrangle, Valley county, Idaho: Idaho Geological Survey, Geologic Map 51,
scale 1:24,000.

ft/day for horizontal conductivity suggesting the model focused on simulating “near-field responses from the Gestrin well test’. Because this is an important area of the model, between Hangar Flats and the RIBs, more layers should have been added in the alluvium and underlying fractured bedrock to better capture/simulate the near and far-field conditions, as both near/far-field response will directly affect hydrologic response to proposed mine features like the RIB infiltration and pitlake dewatering and subsequent filling/spillover.

- Figure 6 shows relatively high K specified in bedrock below ALL stream areas within the model. This is very unrealistic and no justification or data provided to support this specification.
- Storage coefficient – 1x10$^7$ 1/ft is incorrect (Table 4-2 in B&C 2018 EC model study), and should instead be a very low number. B&C 2018 EC digital MODFLOW model file inputs indicates it is actually specified as 1e-7 1/ft. However, this number still appears to be unrealistically low by 1 to 2 orders of magnitude. **A key issue with specifying such a low storage number, is that it directly and notably affects estimated mine impacts, such as total pit dewatering/pitlake fill rates and times, timing/magnitude of impacts to wetlands/streams/GDEs, RIB performance etc.**

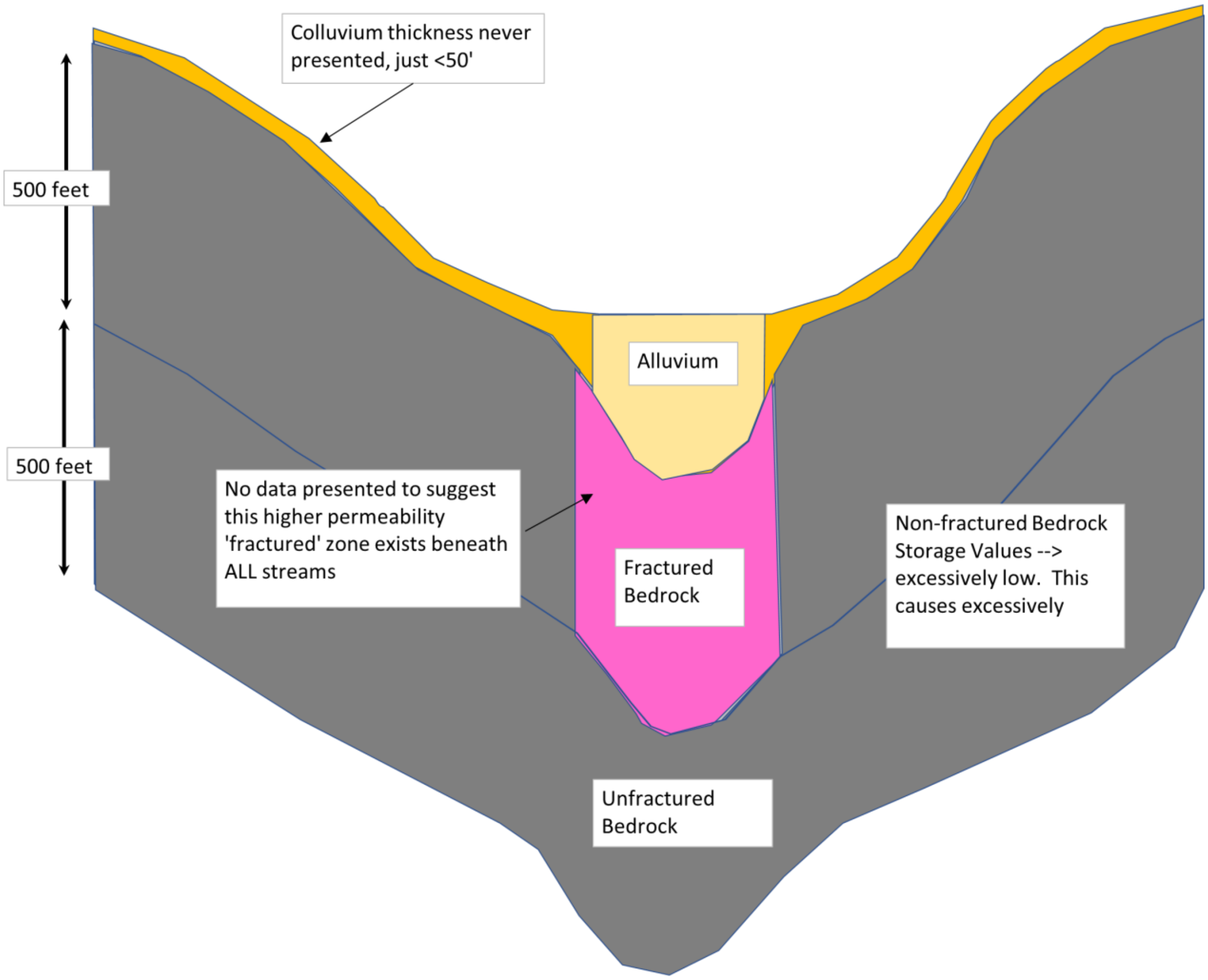
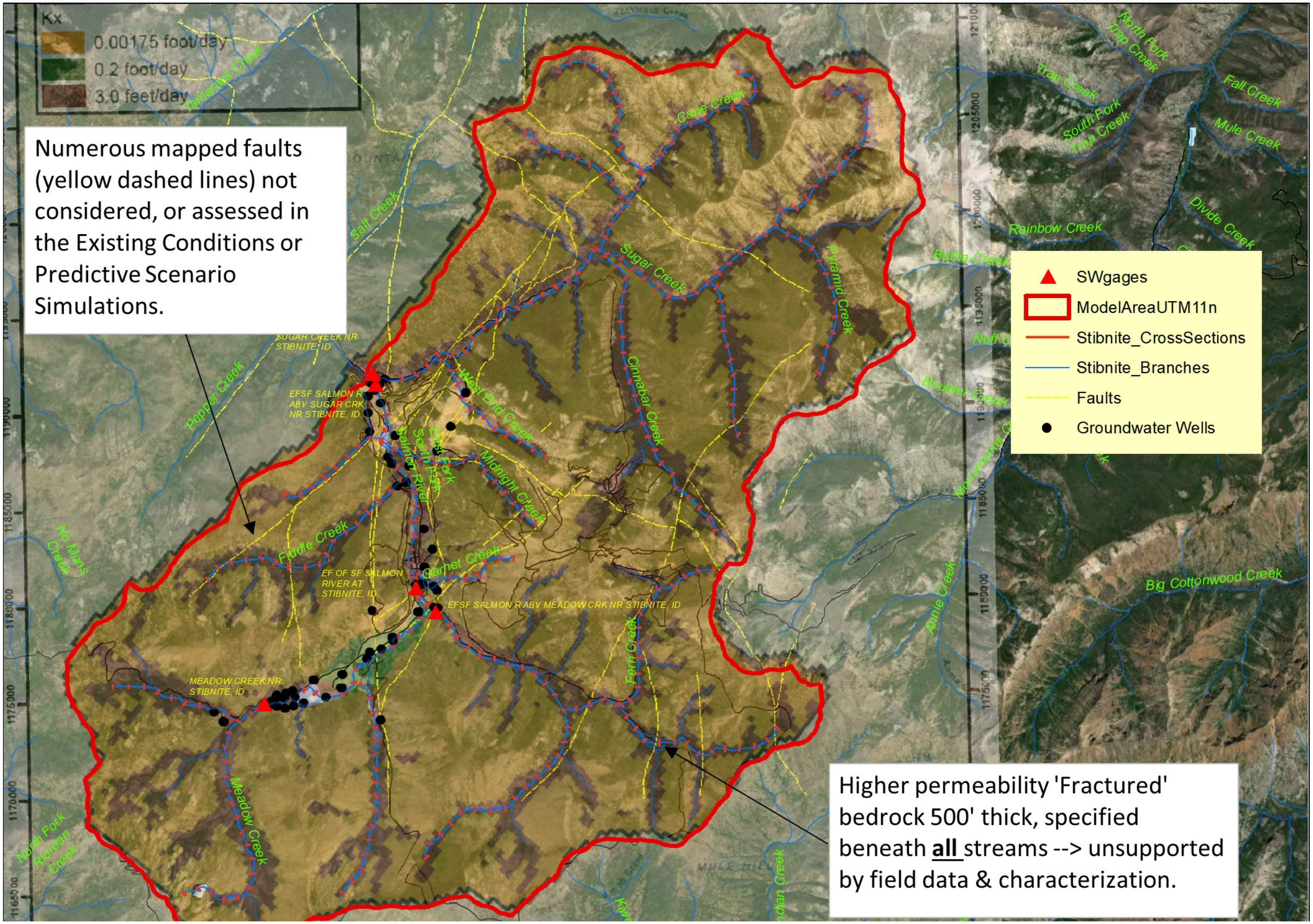


Figure 6. Generalized Subsurface Layering and Hydraulic Property Zones in B&C 2018 Existing Conditions modeling study.



Numerous mapped faults (yellow dashed lines) not considered, or assessed in the Existing Conditions or Predictive Scenario Simulations.

Higher permeability 'Fractured' bedrock 500' thick, specified beneath **all** streams --> unsupported by field data & characterization.

Figure 7. Layer 2 (Fractured/Non-Fractured Bedrock) Spatial Distribution of Hydraulic Conductivity. Higher permeability specified beneath **all** stream drainages.

### 4.7.4 Physically Incorrect and Unrealistic Specification of Recharge and Runoff as Boundary Conditions to the MODFLOW model

#### 4.7.4.1 Physically Unrealistic/Incorrect Calculation of Recharge

Even if the methodology employed by B&C 2018 in the EC modeling were based on some underlying valid methodology (not reported here), it is unclear why more recent, robust USGS monthly water balance methods were not used to calculate the spatial/temporal variation in recharge for the Existing Conditions modeling (Westenbroek et al, 2010[17]), which rely on well-established, physically-based factors (i.e., actual soil hydraulic data, vegetation and slope among others) and equations of flow.

The presumed zonation of groundwater recharge into 'Valley' and 'Hillslope' areas (see page 3-3 in 2018 B&C EC modeling – "*Recharge and surface runoff were further varied between upper-basin and hill slope areas (<u>assumed to have a greater percentage of surface runoff and less recharge</u>) and alluvial valleys (<u>assumed to have greater recharge and less surface runoff</u>).*") is not only physically incorrect, it's also unrealistic, entirely supported by field data and characterization, or based any sort of well-establised/published analytical/numerical methodologies. No methodology was presented or referenced in these calculations, yet many methods and books have been written on the subject. Calculating the spatial distribution and dynamics of groundwater recharge is one of the most challenging and complex hydrologic processes associated with hydrologic modeling (Simmers, 1988[18]), but critical to achieving acceptable calibration (Healy and Scanlon, 2010[19]). The USGS (Flint et al, 2004)[20] has developed a commonly used method called the Basin Characterization Method (BCM) to estimate recharge based on many known factors. **Importantly → the MIKESHE model shows substantial differences in these presumed recharge values and zonations (see Section 5.2.1.4), and calculates recharge in a much more robust, physically-based manner as shown through research** (Prucha, 2002[21]).

#### 4.7.4.2 Physically Unrealistic/Incorrect Calculation of Surface Runoff

Similar to issues outlined in the previous section on recharge, the B&C 2018 EC modeling surface water runoff, estimated as what remains after subtracting the non-physically-based estimate of 'maximum recharge' from 'available water' is physically incorrect and with no apparent technical basis, but also inconsistent with current hillslope hydrology literature by leading researchers[38,39].

---

[17] Westenbroek, S. M., V. A. Kelson, R. J. Hunt, and K. R. Bradbury (2010), SWB—A modified Thornthwaite-Mather soil-water balance code for estimating groundwater recharge, U.S. Geol. Surv. Techniques and Methods 6–A31, 60 pp. [Available at http://pubs.usgs.gov/tm/tm6-a31/.]

[18] Simmers, I., 1988. Estimation of Natural Groundwater Recharge. Springer Netherlands.

[19] https://pubs.er.usgs.gov/publication/70189200

[20] Flint, A.L., Flint, L.E., Hevesi, J.A., and Blainey, J.M., 2004, Fundamental concepts of recharge in the Desert Southwest: a regional modeling perspective, in Groundwater Recharge in a Desert Environment: The Southwestern United States, edited by J.F. Hogan, F.M. Phillips, and B.R. Scanlon, Water Science and Applications Series, vol. 9, American Geophysical Union, Washington, D.C., 159-184.

[21] Prucha, R., 2002. A Conceptual and Modeling Framework for Investigating Recharge in Arid/Semi-Arid Environments. Ph.D. Dissertation. University of Colorado, Boulder (Used MIKE SHE to simulate integrated behavior and recharge response in a large arid/semi-arid basin flow system in Arizona).

Current theory on hillslope hydrology in snowmelt mountainous terrain conclusively shows that much of the streamflow response, particularly the entire rising limbs on hydrographs derives from in-place groundwater, effectively pushed out by rising  discharge, instead of overland runoff[39].

MIKESHE results (Section 5.2) support higher recharge rates, relative to runoff, especially in upland overburden areas, not directly tied to larger drainages, and much lower net recharge in valley areas (even negative values, where AET exceeds Recharge).  Clearly the dynamics of snowmelt stream flows and source of waters is far more complex than the spreadsheet water balance tool used to drive the B&C 2018 EC modeling response.

This is a significant flaw in the existing conditions model (and all subsequent predictive models based on the existing conditions model).  By presuming assumed monthly surface catchment recharge and runoff (mostly spring and fall periods), incorrectly forces the MODFLOW model to generate losing areas in most drainages upstream of the major drainages (i.e., Meadow Creek and EFSFSR), when they should be gaining during this period due by increased baseflows (i.e., red cells on Figure 8 denote areas where streams lose to groundwater, when they should be gaining from due to higher ratios of baseflow to runoff.  **The monthly timestep used in the spreadsheet tool doesn't simulate these effects, which dominate downgradient and downstream hydrologic response.  If these are incorrect, then existing conditions and predictions are wrong.**

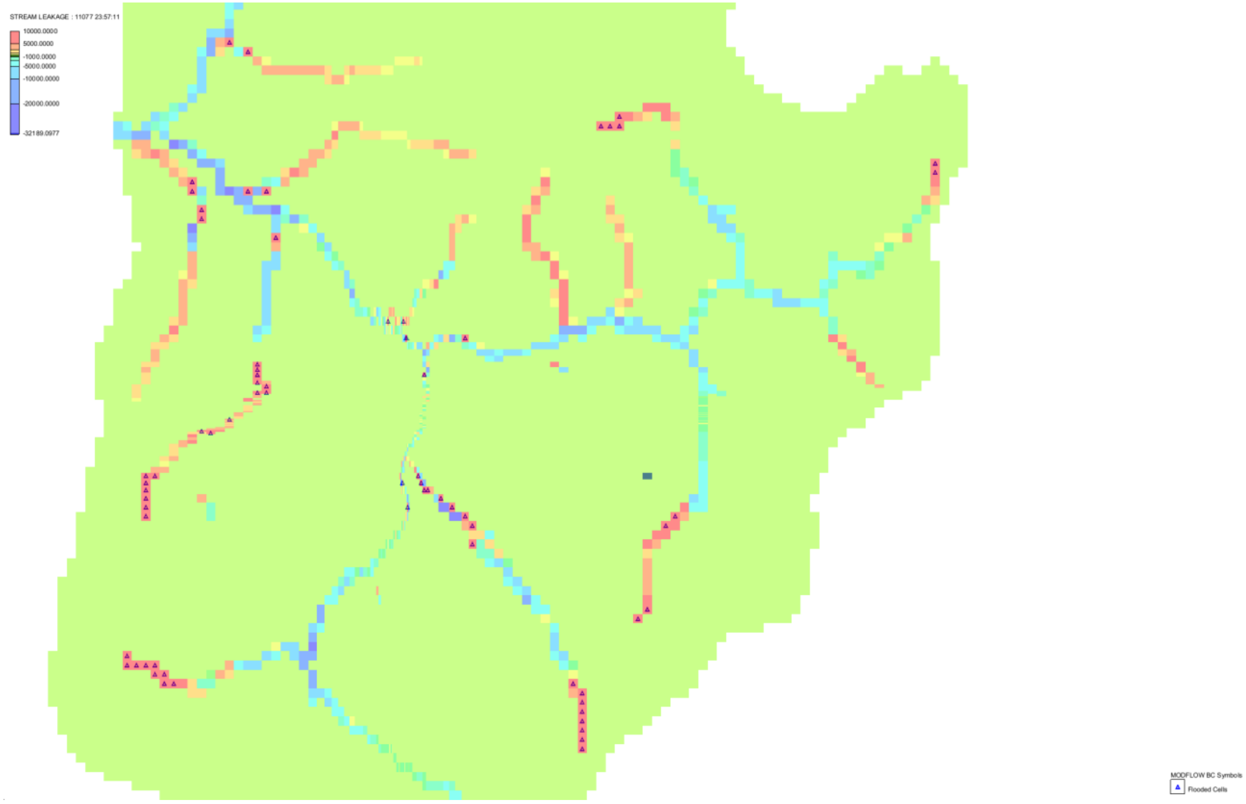


Figure 8.  B&C 2018 EC Model SFR Stream Leakage (ft3/d) at 5/1/2012.  Red areas show losing stream segments, while blue cells indicate streams are gaining.

### 4.7.5 Unclear, Incorrect Setup/Use of the Modflow SFR streamflow routing package

A number of issues were identified in the use and setup of the MODFLOW SFR package used in the B&C 2018 EC modeling. These include:

- The 2018 B&C EC study appears to use the USGS MODFLOW SFR2 Stream Routing Package SFR2[22], though review of digital model input files shows that neither unsaturated zone flow conditions beneath the streams, nor calculation of dynamics stage (even at monthly time-step) using streambed slope, cross-sectional shape (widths), and hydraulic properties were not utilized. At a minimum, cross-sectional areas should have been specified from available topographic data, both in existing conditions and more importantly in proposed modifications, especially post-closure, when numerous stream segments are re-engineered (i.e., above the TSF/DRSF, and through Hangar Flats and West End pitlakes. This would have better simulated actual flows within streams and flow exchange between stream-aquifer. It would likely also affect stream-temperature predictions.

- A significant issue with the stream flow SFR package setup is the following statement "*Stream stage elevations were assumed to be 2 ft higher than the stream bed elevation (i.e., 2 ft depth of water is assumed for all streams) and were fixed for all stream cells throughout the model simulations*.". The SFR package actually offers more realistic/accurate and advanced capabilities which calculate monthly stream stage, given lateral runoff contributions from various catchments. Instead, when a constant depth is specified, though flows continue to increase downstream, the estimated leakage, or exchange of groundwater and stream is pre-defined to a 2-foot stage, when in reality it would vary. Though a 2' constant stage is certainly simpler to setup/run, it introduces additional errors in the calculation of stream-aquifer flows, and affects net groundwater baseflow contributions to total streamflow.

- In contrast, the MIKSHE model prepared in this review (See Section 0), utilizes detailed surface topography to create a fully hydrodynamic hydraulic network of streams through the model domain, including cross-sections placed approximately every 200 meters. This ensures accurate simulation of stream-aquifer exchange at an hourly climate timestep, which permits realistic evaluation of how mining changes/operations and post-closure could impact system hydrology, even for all individual storm or rapid spring freshet runoff events.

- Streambed conductance values are important/sensitive controls on the rate of flow exchange between the groundwater and surface water in streams. Yet B&C authors failed to report the final calibrated spatial distribution of these values, and the basis for determining these values (i.e., from field data/characterization) and later modified through the process of calibration. Standard practice in modeling requires transparently disclosing such critical modeling information.

---

[22] Niswonger, R.G., and Prudic, D.E., 2005, Documentation of the Streamflow-Routing (SFR2) Package to include unsaturated flow beneath streams—A modification to SFR1: U.S. Geological Survey Techniques and Methods 6-A13, 50 p.

### 4.7.6 GDE seepage/spring flow not simulated, and therefore not evaluated in the DEIS

Springs and seeps do not appear to have been simulated as discharge points in the Modflow model. It would have been more appropriate, and industry standard practice to use the Modflow Drain package to calibrate noted at these areas (i.e., DEIS Chapter 4, Figure 4.8-29). Not simulating discharge in these areas, and the re-infiltration downhill from these seeps/springs would cause the Modflow flow model to over-estimate heads in these areas, and under-estimate nearby groundwater baseflow discharge to streams.

### 4.7.7 Estimation of Actual Evapotranspiration Flawed and without technical basis

**Evapotranspiration (ET) from Groundwater is Not Simulated**

AET loss is COMPLEX and spatially distributed and highly variable throughout the year, and groundwater loss to atmosphere (AET) is a major component of watershed hydrologic cycles, typically second only to total precipitation. It is standard practice to include dynamic simulation of ET from the saturated zone using the Modflow ET package, which removes groundwater from the model based on, dynamic water table depths, Max ET rate, extinction depth (i.e., typically meant to correspond to different vegetation root depths), and ET maximum surface. Yet B&C 2018 did not simulate spatially-distributed dynamic ET loss from groundwater, but instead chose to remove PET from total available rainfall/snowmelt **BEFORE** water infiltrates/recharges and runs off from the system. This completely over-rides actual well known/established physical processes/equations of flow known for many decades. As a result, predicted groundwater levels are incorrect in areas where roots intercept water depths (i.e. stream and wetland areas). **This is a major flaw in the B&C EC conceptualization and model setup, and affects all predictions.**

Calculation of AET is in fact, a critical water balance component in most hydrologic models, and a complicated function of complex climate inputs (generally accounted for in more robust estimates of PET, like the standard ASCE or FAO Penman-Monteith equation[23]), soil properties (i.e., soil types, layering, moisture contents, unsaturated zone hydraulic properties), precipitation, groundwater depths with time, and vegetation properties (i.e., leaf area index, root depth density with depth, crop coefficients, types, saturation, residual and field and wilting point moistures, canopy properties etc). In single-process codes like MODFLOW, AET is typically simulated either using the standard EVT package, which calculates AET on a cell-by-cell basis, as a function of groundwater depth, maximum evapotranspiration rates, and plant root depths, or by specifying net-recharge, where AET is calculated on a cell by cell basis, and then removed from applied recharge. Importantly, assessing sub-daily impacts at specific locations in the model is strongly influenced by correct calculation of AET. In riparian zones, groundwater loss to AET and baseflow discharge compete against each other, as a function of groundwater depth. Consequently, without directly simulating AET in all cells, groundwater models likely overestimate baseflow loss, and incorrectly parameterize stream-aquifer conductance values. Omitting this critical process (a conceptual error, especially in semi-arid climates) prevents estimation of mine impacts on phreatophyte-dependent riparian vegetation. This is a major oversight in the DEIS evaluation of impacts at GDEs.

---

[23] http://www.fao.org/3/X0490E/X0490E00.htm

## 4.8 Model Calibration Issues

A number of issues identified with model calibration are summarized here.

### 4.8.1 Calibration Approach Flawed and Non-unique

Calibrating groundwater flow models to only hydraulic heads, which are spatially biased with higher density near the proposed mine, and sparse further from the mine is well known to produce non-unique solutions.[24] The non-unique solution is typical of groundwater models where recharge and hydraulic conductivity values are highly correlated[25]. Doherty and Hunt, 2010[26] indicate that non-unique solutions can be addressed by adding other types of calibration data (i.e., surface water discharge, water quality data etc).

Representing seasonally dynamic gaining/losing surface water flows as 'drain' cells in the groundwater model, fails to account for stream recharge in losing reaches. This in turn forces incorrect adjustments of hydraulic parameter values to compensate, and further degrades calibration and therefore reliability of the groundwater model for predictions.

### 4.8.2 Adequate Calibration Data Lacking

The main focus of the DEIS is to estimate potential changes to the surface/subsurface hydrologic system, or GDEs affected by mine drawdown and changes to surface flows. Despite this objective, virtually no observation data for either surface water, or groundwater is available at, or near GDEs to constrain calibration in these critical areas. This is a major flaw in the overall model calibration approach and should have been addressed in the DEIS.

Other major mine DEIS modeling efforts (i.e., Rosemont mine[27]) attempt to reproduce spatial distribution and magnitudes of observed baseflow, but the spatial distribution and long-term (i.e., multiple years) of surface water flow (or stage) data appears inadequate to assess even flow along the entire extent of the three main drainages potentially affected by the mine dewatering/TSF (Queen Creek, Mineral Creek and Devils Canyon).

### 4.8.3 Calibration Target Datasets

---

[24] Castro, M. C., and P. Goblet, Calibration of regional groundwater flow models: Working toward a better understanding of site-specific systems, Water Resour. Res., 39(6), 1172, doi:10.1029/2002WR001653, 2003

[25] Jyrkama, M. I., and J. F. Sykes (2006), Sensitivity and uncertainty analysis of the recharge boundary condition, Water Resour. Res., 42, W01404, doi:10.1029/2005WR004408.

[26] Doherty, J.E., and Hunt, R.J., 2010, Approaches to highly parameterized inversion—A guide to using PEST for groundwater-model calibration: U.S. Geological Survey Scientific Investigations Report 2010–5169, 59 p.

[27] O'Brien, G. 2010a. Technical Memorandum: Groundwater Flow Model Construction and Calibration. Document No. 198/10-320874-5.3. Prepared for Rosemont Copper Company. Tucson, Arizona: Tetra Tech. July 26.

Apparent inconsistency between number of GW targets – EC modeling report. 2017 SGP Water Resources Summary report page 8-2 indicates 31 wells used. But EC modeling report indicates 55 wells. Apparently transient dataset is 65 wells (reference???). A clear/transparent discussion of calibration wells, and expected range of calibration accuracy should have been presented.

- Figures 2-3a and 2-3b and Tables 2-1 and 5-1 in the 2018 B&C EC modeling report do not appear to include higher priority calibration well water level data (i.e., in mined areas that will change notably) clearly evident on Figure 2-2 of the SPF 2017 Groundwater Baseline Study in:
  - The West End area (MWH-B21 (multiport), MWH-B22 (multiport), and
  - MWH-B17 and MWH-B16 (multiports, within Yellow Pine footprint, and
  - Well MWH-A06 (over Hangar Flats pit area, or former historical mine works). In addition, MWH-A06 appears to be labelled well MW-A07 (from 2017 B&C Water Summary Report) appears to be labelled MW-A06 in the B&C 2017 Water Resources Summary study, Figure 8-1.

  Using parameter values as specified in the B&C 2018 EC modeling study, notable calibration errors occur in the West End and Yellow Pine pit areas in the MIKESHE modeling effort (10's of meters to high or low), which indicate the baseline EC model parameterization in this area is incorrect and needs further calibration. It's unclear why these well data were not used to guide calibration in this highly mine impacted area.

- No discussion is presented, describing required calibration target locations, distributions and accuracy are required to ensure reliable/accurate simulation of existing conditions and changes in conditions due to mining in sensitive environmental areas (i.e., specific wetland areas, critical fish habitat, geochemical source areas, sensitive areas of heat flow/temperature).

- Why weren't gaining/losing reaches and associated flow measurements (i.e., Figure 7-14 and 7-15 in B&C 2017 Water Resources Study) used to calibrate the B&C 2018 Existing Conditions monthly coupled Meteoric Water Balance spreadsheet-Modflow model? This is a critical dataset that the baseline model should have reproduced, before attempting to use this model to predict mine impacts/closure conditions.

- Why weren't seep and spring locations and associated discharge rates used to calibrate the B&C 2018 Existing Conditions modflow model (i.e., Figure 7-4 in B&C, 2017 Water Resources Summary report) to any of these numerous GDE discharge or head data, if these features represent hydraulically connected locations? Many appear to exceed 20 gpm from the 2012 Seeps and Springs survey, though it's unclear if discharge or heads were monitored over time at any of these important features. This is a notable calibration oversight, which even the mining industry typically attempts to calibrate to. It would have been easy to use the MODFLOW-NWT drain package to simulate discharge at these locations, which could have been compared against the 2012 seep/spring surveyed discharge, or time-varying monitoring data if it had been identified early on as a critical environmental indicator to model, like in other mining DEIS studies.

- Why weren't available vertical, and even horizontal gradient data (See Table 8.3 and 8.4 in the B&C 2017 Water Summary Report) over different time periods used to calibrate the B&C 2018 Existing Conditions model, which would have further reduced solution non-uniqueness issues described in DEIS Section 4. Calibrating to vertical gradients, especially in stream areas is industry standard practice and invaluable in showing where up-/down-welling areas occur throughout the year, which should have been included in the stream temperature evaluation, because fish spawning/habitat are typically quite sensitive to these areas.

- Why weren't snow course data collected and used to calibrate the hydrologic model? MIKESHE is able to do this, and is critical to reproducing snowmelt runoff response in both recharge and to a lesser extent, direct runoff (see Section 5.2.1.5).

- GW baseline report → transient GW levels over several years. Apparently unused by monthly 'transient' modflow model of existing conditions. WHY NOT??

- Why weren't transient head data used to calibrate the modflow model (i.e., see Appendix A, SPF 2017 Groundwater Hydrology Baseline Study)? Calibrating to transient head data are critical for determining appropriate unconfined and confined aquifer storage terms. Properly calibrated storage terms are essential parameters strongly influencing a variety of important DEIS mine impacts, including:

  a) Total water management
  b) Mine dewatering times/rates
  c) RIB infiltration capacity/response
  d) Times for pits lakes to fill up, and
  e) Stream response

Wels et al, 2012[6] indicate (page 140, P2) "*The calibration acceptance criteria refer to model goodness of fit using quantitative (statistical) thresholds and qualitative goodness of fit requirements. These criteria are project-specific, depend on the modelling objectives and data availability, and should be defined before model calibration*." No discussion or description of required calibration acceptance criteria (i.e., for Phabsim simulations, or Geochemical simulations) were provided.

### 4.8.4 Transient Head Calibration Missing

Wels et al, 2012 indicate (page 148, P1), "*Transient calibration can provide improved confidence in model results, particularly in cases where seasonal effects may be important*". B&C 2018 EC modeling failed to calibrate their model to available transient groundwater levels from 2011 to 2015 (i.e., SPF 2017 Groundwater Hydrology Baseline Study, Appendix A – well summary, and

Attachment A – hydrographs). The MIKESHE model used all of these transient data to guide calibration; several examples of transient calibration are shown in Section 5.2.1.1. These data greatly aid calibration of aquifer storage parameters (i.e., specific yield and specific storage) that strongly influence various subsequent mining/post-closure mine impact predictions including:

- Dewatering rates
- Time to dewater
- Extent/magnitude/timing of groundwater level changes due to pit dewatering.
- Time to fill pitlakes and decant,
- Time and nature of changes to groundwater levels and seepage associated with DRSF/TSF features
- Infiltration/storage capacity of RIBs
- Changes in streamflow
- Total water management

MIKESHE modeling results show that upper, more fractured bedrock probably likely has storage values on the order of 1- to 2-orders of magnitude higher than the B&C EC model indicates (at least where the somewhat spatially-biased, near valley-floor wells are located). A clear indication the B&C EC storage values were too low (i.e., 1e-7 1/ft) at many wells is that MIKESHE over-simulates the seasonal water level fluctuation by many meters.

### 4.8.5 Claims of Calibration – Adequate, when they aren't for intended purposes/setup problems

Many examples of EC model is calibrated stated throughout – yet, do not reflect numerous setup problems, limited calibration data, monthly timestep etc. No discussion up front on what level of calibration is needed to fully assess environmental impacts is provided (i.e., GDEs, stream baseflow changes, peak flow modifications etc – as they impact ecosystems.).

### 4.8.6 Gaining/Losing Response.

No attempt was made to calibrate the existing conditions model to gaining/losing data (i.e., B&C 2017 SGP Water Resources Summary, Figures 7-14 and 7-15, showing October 1-7, 2012 and August 13-19, 2015 gain/loss sections, respectively). This is essential calibration data for key DEIS evaluation. The setup/application of the existing conditions model at a monthly timestep, and loosely coupled to a lumped-parameter spreadsheet estimate for surface runoff, assigned at specific points in the MODFLOW-NWT model's SFR stream network would not be expected to however simulate such response with any degree of accuracy/confidence.

Review of B&C 2018 digital MODFLOW data files permitted closer review of estimated leakage rates into and out of the stream (i.e., gaining and losing reaches, respectively) for each month from 1/1/1985 to 1/1/2018. Review of the Stream Leakage (cell by cell flow output) data indicates

#### 4.8.7 Surface Water Discharge Calibration Metrics Missing

What are important metrics for assessing environmental impacts – i.e., Phabsim assessments? Geochemical assessments? Flooding? Design/operation assessments?

Qualitative plots of simulated and observed monthly discharges (time-averaged over the month) don't compare that well (i..e they typically entirely miss the fall runoff events), and given other notable shortcomings in the EC modeling, don't appear to reflect reality.

#### 4.8.8 Presentation of Calibration Results Incomplete/Misleading

Model performance and reliability based on model-wide calibration statistics of only head data gives a misleading and unreliable sense the model is adequately calibrated for intended purpose of evaluating impacts at GDEs. For the high degree of hydrogeologic complexity of the subsurface system, including multiple offset faults, perched, shallow and deep aquifer units and historically complex dewatering in the area, the number, locations and depths of calibration targets is inadequate, particularly in key target GDE areas, the main focus of the groundwater modeling evaluation. For example, Table 3.6 in the WSP, 2019 report indicates Residual Mean in the Apache Leap Tuff is -14 ft, indicating on average, the model over-estimates heads in this shallow aquifer. Yet, closer inspection of transient well hydrographs included in Appendix C of WSP, 2019 closer to surface drainages (i.e., DHRES-08, DHRES-10, DHRES-11, DHRES-12, DHRES-17 and DHRES-18) indicates simulated differences more than 100 to more than 600+ feet

### 4.9 Predictions Incomplete and Misleading

A number of issues were identified in the DEIS regarding model predictions that rely on the calibrated B&C 2018 Existing Conditions model. **Importantly → all of the issues pointed out with the development and calibration of the Existing Conditions model translate directly into all of the predicted impacts and water balances both during and post-closure of the mining areas. As a result, all predictions using the 'calibrated' EC hydrologic model have significant errors and substantial uncertainty. The DEIS should require development of a much more rigorous EC model, before considering any of the subsequent predictions with the modified EC model.**

#### 4.9.1 SPLNT temperature modeling.

Several issues were identified in the stream temperature modeling:

a. Doesn't consider substantial increase in temperatures due to climate change (see MSHE results Appendix A). Increased air temperatures, will notably increase temperatures of surface and groundwater, on the range of increased temperatures predicted in this study!!

b. Steady flow conditions are entirely unrealistic, particularly given the large influence of snowmelt, which changes notably with future climate change. It is critical to simulate at least daily river flows, and the stream flow and heat balance response to all storms throughout the year, including snowmelt freshet. An integrated hydrologic/hydraulic code that simulates dynamic flows and heat balance should have been used to assess multiple years of variable climate, for example as was done at Silver Creek, Idaho[28], and Pebble Mine, AK[29].

c. Any designs/operations, restoration/reclamation during/post-closure must account for increasing temperatures. It must also account for large-scale FLOODING EVENTS, like the 1960s event that caused Blow Out Creek dam failure!

### 4.9.2 Issues Identified with Predictions of Hydrologic Impacts During Mining/Post-Closure

**Predictive uncertainty missing.** B&C 2018 Revised Final PA study fails to present a range of predictions that both reflect the numerous flaws in the B&C 2018 EC model and the significant uncertainties associated with the various model input parameterizations, conceptualizations, and external boundary conditions. Impacted predictions in this report/DEIS.

**Technical details and/or analysis of major mine features are missing in DEIS.** Technical details associated with primary mine features such as TSF, DRSFs, RIBs, Blowout Creek Restoration plans. For example:

- **Blowout Creek Issues**
  The proposed plan to restore Blowout Creek (or East Fork of Meadow Creek) appears flawed:
  - Figure 8-4, 2016 SGP PRO report shows details of a coarse rock french drain that would be placed through the main sediment source area, between the former dam and Meadow Creek. MG also proposes raising water levels above this feature, near the previous dam to enhance wetlands in this area.
  - No coupled groundwater-surface water hydraulic analysis appears to have been conducted to evaluate whether the proposed modifications would actually reduce sediment, or enhance it.
  - Visual examination of this area in Google Earth (see Figure 9) strongly suggests the main source of sediment are the exposed sides of the drainage as shown, which are generating rills/gullies. In addition, these appear to be bounded by the trace of the Meadow Creek Fault Zone (two green lines mapped by Stewart et al, 2016[16].
  - Raising the groundwater levels above this sediment source area is a bad idea, and would only increase potential downcutting through this area. By design, this area should remain a losing stretch, year round to reduce instabilities.
  - A much better alternative, apparently not considered here, would be to:
    - regrade and revegetate these exposed areas, stabilizing upper top of slope
    - consider piping flows through unstable area,

---

[28] Loinaz, Maria C et al. "Integrated Flow and Temperature Modeling at the Catchment Scale." Journal of hydrology (Amsterdam) 495 (2013): 238–251

[29] Wobus, C., Prucha, R., Albert, D., Woll, C., Loinaz, M., Jones, R., 2015. Hydrologic Alterations from Climate Change Inform Assessment of Ecological Risk to Pacific Salmon in Bristol Bay, Alaska. Submitted to PLOS ONE May 2015.

    - include surface water diversions above upper top of slopes along exposed slopes to account for future post-fire flooding in the area, which would only further degrade the area.

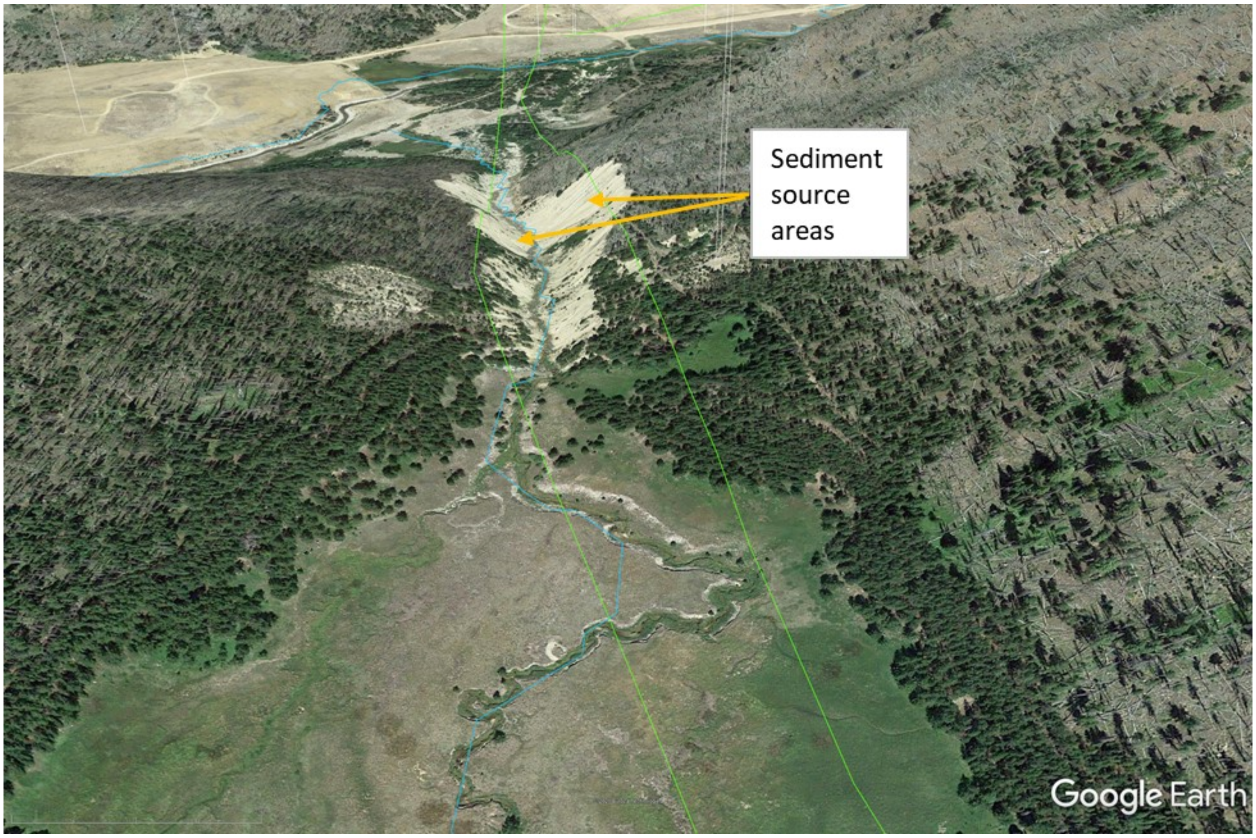


Figure 9. Proposed restoration area of Blowout Creek. Green lines represent Meadow Creek Fault Zone.

- **TSF/DRSF underdrain Issues**

  Figure 2-2 in the B&C 2019 Final SGP PRO Alternative Modeling Report shows the post-closure TSF and DRSF

    - Post closure failures of TSF underdrain would cause significant problems that the DEIS does not address. For example, If the underdrains become clogged over time (say by mudflows caused by forest fires uphill, or even the geosynthetic clay liner placed over the ~1 foot thick coarse rock layer on top of the original ground surface, which fills in voids within this rock layer), saturation levels would likely build up within the tailings due to increased pressures and leakage into the TSF material from continuous year-round lateral groundwater inflows from adjacent alluvium/fractured bedrock.
    - Details of the PA or modified PRO design for these features (i.e., geosynthetic covers on top, or just above the underdrains) doesn't appear to have been modelled or evaluated to assess behavior as intended, or during such likely failures as above. The EC model has notable errors through calibration, and results are highly uncertain.
    - Geosynthetic liners on top of the TSF

**Estimates of recharge and runoff at mine features incorrect/uncertain.** Chapter 4 in the DEIS, page 4.8-12 indicates that post closure modeling versions of the B&C 2018 EC model added the pit lakes and "*adjusting recharge to various areas that would be subject to reclamation, modification and changing stream routing*". Yet the underlying B&C 2018 EC model estimated recharge incorrectly (see Section 4.7.4.1) using only historical climate data and assumed recharge rates. They should have developed accurate estimates of recharge, AET and runoff based on physical equations of flow and physically-based parameters associated with design (i.e., specific hydraulic properties, regraded slopes, specific vegetation types etc). As a result, predicted hydrologic response to specific proposed mining features (during & post-closure) are unrealistic and highly uncertain. This is an important deficiency in the DEIS.

**Monthly timesteps inadequate for DEIS evaluations**. All predicted changes to system hydrology during mining and post-closure are at a monthly timestep, which omits evaluation of impacts to sub-monthly, or importantly to event-level hydrology, critical to assessing impacts to dependent ecosystems (wetlands, fish, habitat etc).

### 4.9.3 Effects of Climate Change not Evaluated

Page 4.8-11 in Chapter 4 of the DEIS indicates that predicted mine impacts are evaluated over a range of historical climate variability, but incorporate predicted future climate change (i.e., IPCC estimates – see Section 5.3), which ADDS significant changes to the historical variability. As a result, the DEIS fails to assess a realistic range of mine impacts and water management due to climate change.

### 4.9.4 Use of 5-foot Overburden and 10-foot Bedrock drawdown Contour during Pit Dewatering under-estimates the number/magnitude of GDE impacts

At least a simulated long-term 1-foot drawdown contour should have been used in the identification of GDEs. GDEs, or private wells experiencing even a 1' drawdown could have significant negative impacts. A simulated 1-foot drawdown contour (or lower) was never shown in the DEIS, but probably shows significant effects of model boundary effects, implying the model extent should have been expanded to avoid any influence over internal calculations as is standard modeling practice. Using the 10-foot drawdown contour to define impacts is highly biased, and likely removes many GDEs from further evaluation of impacts/mitigation. The explanation that drawdowns less than 10-feet are imprecise in the DEIS (see page 301) is flawed. Groundwater models are precise, but suffer from accuracy issues. The accuracy at 1-foot drawdown is the same as 10-feet. A predictive uncertainty analysis would effectively provide a means of adding a +/- around drawdown contours.

### 4.9.5 Sensitivity Analysis Biased and Misleading

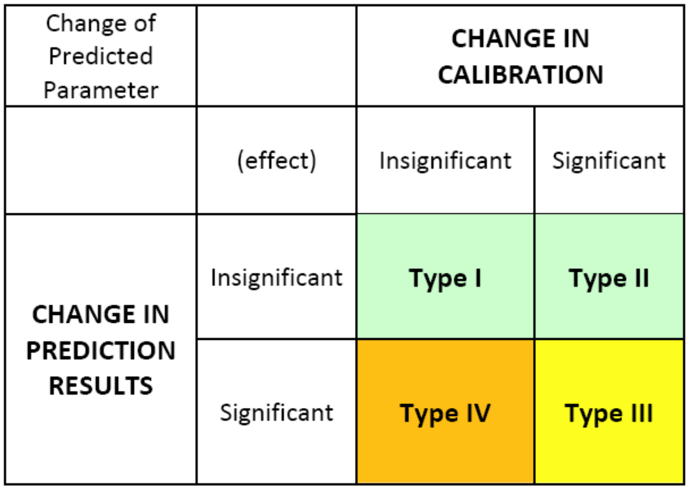
B&C sensitivity study failed to compare effects of a change in selected sensitive parameter on specific hydrologic response at the same locations for both calibration and model prediction, so that they could then assess which type of sensitivity responses resulted (see Table 8-1 below), particularly the Type IV sensitivity which indicates the model predictions shouldn't be relied on. One example could have been changing K and S hydraulic parameters in the RIB area, and comparing significance of relative local changes in streamflow and/or head response for calibrated model and predictive model.

Page 176, P3 Wels et al, 2012 states "*Type IV is a cause for concern because non-uniqueness in a model input might allow a range of valid calibrations, but the choice of value significantly impacts model prediction. It is important to determine the actual value of this parameter and not rely on model calibration to estimate this parameter.*" B&C 2019 sensitivity modeling failed to address Type IV sensitivities, where calibration sensitivity is insignificant, but prediction changes are significant.

Highly biased selection of parameters to evaluate.

- MSHE modeling showed subsurface layers/configuration notably flawed – therefore, the decision to change just hydraulic conductivity values of specific geologic material zones is flawed.
- B&C failed to first conduct a scaled sensitivity analysis to rank the numerous model inputs (i.e., parameters, boundary conditions, layering) specific model responses are most sensitive to. Instead they just focused on K values of each zone.

**Table 8-1: Four Sensitivity Types (after Brown, 1996)**



| Change of Predicted Parameter | | **CHANGE IN CALIBRATION** | |
|---|---|---|---|
| | (effect) | Insignificant | Significant |
| **CHANGE IN PREDICTION RESULTS** | Insignificant | **Type I** | **Type II** |
| | Significant | **Type IV** | **Type III** |

- Typically other DEIS sensitivity analyses adjust other inputs such as recharge (by zone), streambed conductance values, storage terms, evapotranspiration rates, all of which could dominate modelled response in either, or both calibration and predictive models.

Confusion between sensitivity analysis and uncertainty analysis. Authors have produced figures (i.e., Figure 4-6, 4-8 and 4-10 – Dewatering Rates at various pits, and Figure 4-12 RIB Infiltration) that incorrectly imply a range of uncertainty for each prediction. The problem is that they have not required that each sensitivity simulation maintain calibration, which means their results at best, give a misleading sense of uncertainty.

### 4.9.6 Predictive Uncertainty Evaluation Missing

The *ERM 2019 Peer Review* evaluation indicated various issues with model uncertainty, particularly related to Faults. Chapter 4 (Section 4.8.8) in DEIS failed to address this uncertainty, and instead indicated this was outside of the budget/time constraints (i.e., page 4.8-72, Paragraph 2). Modern uncertainty analysis techniques are routinely applied in the mining industry and are not unrealistically costly/timely.

The DEIS appears to acknowledge uncertainty in their modeling predictions of drawdown extent, but then failed to provide a range of predictions for all predictions. Other modeling efforts also appear to have failed to consider any type of predictive uncertainty, despite substantial calibration errors and high input uncertainty. The DEIS should have required a comprehensive approach to dealing with any modeling uncertainty in all model predictions. All of the models developed and referenced in this DEIS (and supporting documents) have numerous assumptions and inputs, each of which translate into prediction uncertainty, but none address the substantial uncertainty in predictions, let alone even identifying and tracking all sources of uncertainty.

Evaluation of hydrologic model prediction uncertainty is critical, yet B&C 2018 EC modelers confused sensitivity evaluation for standard/formal predictive uncertainty analysis. It is important to note that the non-uniqueness of the groundwater flow model calibration leads to many equally valid predictive solutions, using different model inputs. Assessment of the range of possible impacts of the mine on surrounding hydrology (and WQ) is therefore, inadequate and unreliable. It is misleading/incorrect to assume flawed/unreliable model simulated drawdowns above 10 feet are accurate, and those below are inaccurate. GDEs are very sensitive to groundwater levels – and even a 1-foot change likely significantly changes spring/river discharge or even presence. Gabora et al, 2014[30] appropriately used a Monte Carlo method to predict an entire range of simulated pit model inflows, while maintaining calibration.

The reliability of the model findings is implicitly tied to the accuracy of the model, which by default is uncertain, like all models. Model accuracy can be improved by collecting more data, increasing discretization and better reproducing observations, but in reality this is impossible to achieve, given that models are simplifications of flow systems, and data will always be limited. As such, it is far more important for RCM consultants to acknowledge uncertain model predictions, and instead conduct a detailed and robust predictive uncertainty analysis which focuses not just on predicted groundwater inflow to the pit lake, but also on predicted response at all other mine

---

[30] Gabora, M., Martin, N., Clements, N. 2014. Application of the Null Space Monte Carlo Method in a Groundwater Flow Model of Mine Pit Dewatering. An Interdisciplinary Response to Mine Water Challenges - Sui, Sun & Wang (eds).

components, at the same time. A sensitivity analysis (ASTM D5611[31]) doesn't provide a range of possible predicted responses given ranges of uncertain model inputs like an uncertainty analysis, which constrains realizations to maintain calibration within acceptable targets (Doherty, 2010).

Modelers appear to have confused a predictive sensitivity analysis with a predictive uncertainty analysis. The difference is important, as a sensitivity analysis does not provide a true assessment of model uncertainty (see Neuman and Weiranga, 2003[9], Doherty et al, 2010[33]) – typically perturbations cause the model to fall out of calibration, which make the results unreliable. Yet the authors report a range of output from simulations using unjustified adjustments of selective (i.e., cherry picked) parameters, to imply they've considered the full range of possible impacts at GDEs, despite the modelers using the PEST code (described by code author Doherty, 2010) to help refine model calibration (see page 27, WSP, 2019), they failed to use the same code to conduct a predictive uncertainty analysis.

The failure of this DEIS to require formal uncertainty analyses for all of the modeling predicting impacts to the surrounding environment/GDEs is a major oversight. As Doherty et al, 2010 states "*Central to any decision-making process is an assessment of risk. Such an assessment is impossible without some assessment of predictive uncertainty.*", which clearly supports the need for some type of uncertainty analysis to qualify predictions.

Ultimately, model predictions of impacts on GDEs are considered highly uncertain, due to a combination of the high level of input uncertainty, high conceptual model uncertainty, uncertainty in calibration data, and notable model error. While it appears that the the groundwater modeling workgroup has acknowledged results are uncertain, especially with distance from the mine operations, further evaluation of uncertainty was dismissed in favour of selective sensitivity evaluations (Meza-Cuadra et al, 2018c[32]). Conducting a simplified sensitivity evaluation and then claiming it represents model uncertainty is misleading and understates the value of conducting a formal uncertainty analysis (at GDEs). An uncertainty analysis defines a range of equally valid predictions, which maintain calibration constraints, by adjusting individual/combinations of model inputs, to which the solution is most sensitive. Sensitivity analysis identify parameters that predictions are most sensitive to, but do not bracket a realistic range of **equally possible solutions** that meet objective function constraints (i.e., minimizing the difference between historical and simulated heads), and as such shouldn't be used in lieu of a constrained uncertainty analysis. Conducting a formal uncertainty analysis and providing a qualified range of potential impacts, provides a much better way to inform critical decisions related to mine permitting.

The null space Monte Carlo Constrained Maximization/Minimization method (Doherty et al, 2010[33]) can provide the very important result of conveying the range (maximum – minimum) of

---

[31] ASTM D5611-94(2016), Standard Guide for Conducting a Sensitivity Analysis for a Groundwater Flow Model Application, ASTM International, West Conshohocken, PA, 2016, www.astm.org

[32] Meza-Cuadra, G., C. Pantano, and D. Oliver, 2018c. Resolution Copper Groundwater Flow Model - Sensitivity Analysis. Greenwood Village, Colorado: WSP. November 19.

[33] Doherty, J.E., Hunt, R.J., and Tonkin, M.J. 2010. Approaches to highly parameterized inversion: A guide to using PEST for model-parameter and predictive-uncertainty analysis: U.S. Geological Survey Scientific Investigations Report 2010–5211, 71 p.

equally plausible predictions of impacts at GDEs. The current sensitivity analysis is a) too selective and doesn't consider combinations of sensitive parameters and b) isn't constrained to minimize objective function (i.e., reproducing historical conditions within some value).

The well-known parameter estimation code PEST can be used in conjunction with existing calibrated groundwater models to determine a full range of uncertainty in predicted effects on GDEs using the Null-Space Monte Carlo method (see Doherty et al, 2010). The choice of the target or threshold objective function level at which the model is deemed to be "calibrated" is often subjective (Though targets should be determined based on required accuracy in GDE areas of interest following, for example a baseline study of this flow system that defines minimum environmental flows or changes to the hydrologic/ecologic system, to avoid irreverisble damage).

Doherty et al, 2010 states "The principle that underlies this methodology is illustrated in his figure 6 for a two-parameter system. In this figure, the shaded contour depicts a region of optimized parameters that correspond to the minimum of the objective function. The solid lines depict objective function contours; the value of each contour defines the objective function for which parameters become unlikely at a certain confidence level. Each contour thus defines the constraint to which parameters are subject as a prediction of interest is maximized or minimized in order to define its post-calibration variability at the same level of confidence. The dashed contour lines depict the dependence of a prediction on the two parameters. The constrained maximization/minimization process through which the post-calibration uncertainty of this prediction is explored attempts to find the two points marked by circles on the constraining objective function contour. These points define parameter sets for which the prediction of interest is as high or as low as it can be, while maintaining respect for the constraints imposed by the calibration process."

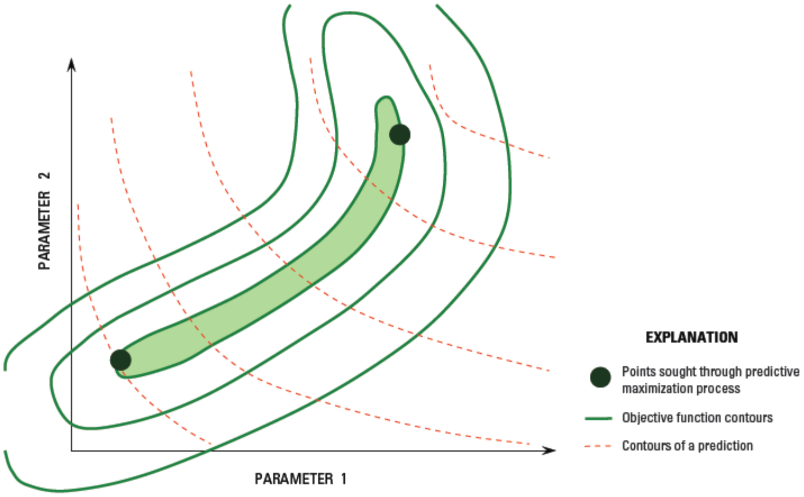


**Figure 6.** Schematic description of calibration-constrained predictive maximization/minimization.

# 5 Development/Application of a fully Integrated Hydrologic/Hydraulic Model of the Stibnite Mine Area

MIKE SHE is an integrated hydrologic code that dynamically simulates coupled groundwater and surface water flow, including recharge, snowmelt, and evapotranspiration (ET) interactions. This dynamic coupling, driven by external spatially distributed hourly air temperature, precipitation, and reference ET, offers distinct advantages over traditional single-process methods (i.e., monthly spreadsheet-based water balance tools, or groundwater modeling tools like MODFLOW). One key advantage is that MIKE SHE simulates more physically-realistic and meaningful changes in hydrologic/hydraulic indicators in response to mining land use changes and operations for each storm event, over many years. This is critical for assessing impacts on the surrounding ecosystem, habitat, and environmental flows[5]. In addition, MIKE SHE is able to assess how mining impacts will affect integrated flows and stream temperature[34,35].

## 5.1 Model Inputs/Assumptions

### 5.1.1 Model Domain/Discretization

The Sugar Creek and EFSFSR upper watershed boundaries (based on National Hydrographic Dataset HUC polygons) were used to define the MIKESHE model boundary, similar to the B&C 2018 existing conditions model and is shown on Figure 14. A regularly spaced grid of 71 m was defined over the flow domain, and reasonably accounts for subsurface complexity and surface water features. A total of 22,069 cells are defined as active in each layer.

### 5.1.2 Surface Topography

A 10-m topographic DEM dataset was mosaiced in ArcGIS over the entire watershed domain, and used to define both the upper overland flow surface, and hydraulic stream network and sections.

### 5.1.3 Subsurface Layers

Initially the same 3 model layers were defined based on information provided in the B&C 2018 existing conditions report (Figures 2-5, Figures 4-4 and 4-5). Contours of overburden thickness were digitized over the extent available (not available for the entire model), and modified in upland/non-valley areas where contours simply indicated <50 feet thick. Initial MIKESHE modeling iterated towards a realistic thickness of overburden in upland areas, required to calibrate the integrated response against transient head and stream discharge data. An upland overburden thickness of 3 meters was eventually specified in all upland areas, and all areas not defined by the overburden thickness map provided by B&C 2018 (Figure 2-5). As a result, virtually all of Sugar Creek watershed was simulated using an overburden thickness of 3 meters. Initial calibration simulations also strongly pointed to the need to include a 10-meter thick layer (4 total

---

[34] 21. Wobus C., Prucha R., Albert D., Woll C., Loinaz M., Jones R. Hydrologic Alterations from Climate Change Inform Assessment of Ecological Risk to Pacific Salmon in Bristol Bay, Alaska. 2015, PLoS ONE, 10(12), 1-21. DOI https://doi.org/10.1371/journal.pone.0143905 https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0143905&type=printable Accessed 6/28/2020.

[35] Maest, A., Prucha, R., Wobus, C., 2020, Hydrogeologic and water quality modeling of the Pebble Mine Project pit lake and surrounding area after mine closure. Minerals 2020, 10

layers simulated in MIKESHE) to represent a more permeable/isotropic weathered bedrock layer, immediately underlying the overburden.

The two remaining layers (MIKESHE Layer 3 and 4) were defined as in the B&C 2018 existing conditions model, effectively at 500 feet (bottom of Layer 2 in B&C report) and 1000 feet (bottom of Layer 3 in B&C report) below the overburden layer bottom. Calibration simulations clearly show that the higher permeability zone within 'fractured' bedrock below streams, as defined in the B&C 2018 EC modeling, is not necessary to reproduce both observed transient head and surface discharge responses well. Further, MIKESHE modeling suggests that it makes more sense to include thicker, higher permeability zones within each well defined stream drainage instead of the unrealistic 500' thick 'fractured' bedrock zone beneath the streams. Data and characterization simply don't justify such an assumption.

### 5.1.4 Subsurface Hydraulic Conductivity Distributions

Hydraulic properties for subsurface layers in MIKESHE were initially defined based on information provided in the B&C 2018 Table 4-2 and Figures 4-7 to 4-9. A key point to developing the MIKESHE model was to:

- First test general variations of the B&C 2018 EC model hydraulic property configuration, and associated conceptual flow model and
- Assess whether an alternative hydraulic property configuration/conceptualization could better reproduce available calibration data. Simulation results showed the lower plot produces better calibrations.

The upper hydraulic property configuration (conceptualization) shown on Figure 10 represents a similar model configuration as the B&C 2018 EC model, while the lower graphic shows a configuration that offers what appears to be a more realistic/defensible conceptual flow system supported by current research Tokunaga et al, 2019[36]. The lower graphic effectively eliminates the unrealistic/unjustified 500' thick fractured bedrock beneath all streams (pink zone removed), and instead promotes thicker and higher permeability stream alluvium overlying a 10 m thick isotropic 'weathered/fractured' bedrock layer, consistent with Figure 1 in Tokunaga et al, 2019. It seems less plausible that upper fractured bedrock would exhibit vertical anisotropy that typically occurs in alluvium systems.

### 5.1.5 Subsurface Storage Terms

Specific yield and storage terms were initially defined the same as in the B&C 2018 EC model, except 10 m thick higher permeability (isotropic) weathered bedrock (layer 2 in MIKESHE model) included higher specific storage (0.0001 1/m). Later simulations showed that higher specific storage values of (~1e-5) for the upper 500 feet of 'non-fractured' rock improved the response of simulated transient heads at observed wells much better (i.e., much less seasonal variability).

---

[36] Tokunaga, T. K., Wan, J., Williams, K. H., Brown, W., Henderson, A., Kim, Y., et al. (2019). Depth- and time-resolved distributions of snowmelt-driven hillslope subsurface flow and transport and their contributions to surface waters. Water Resources Research, 55. https://doi.org/10.1029/2019WR025093

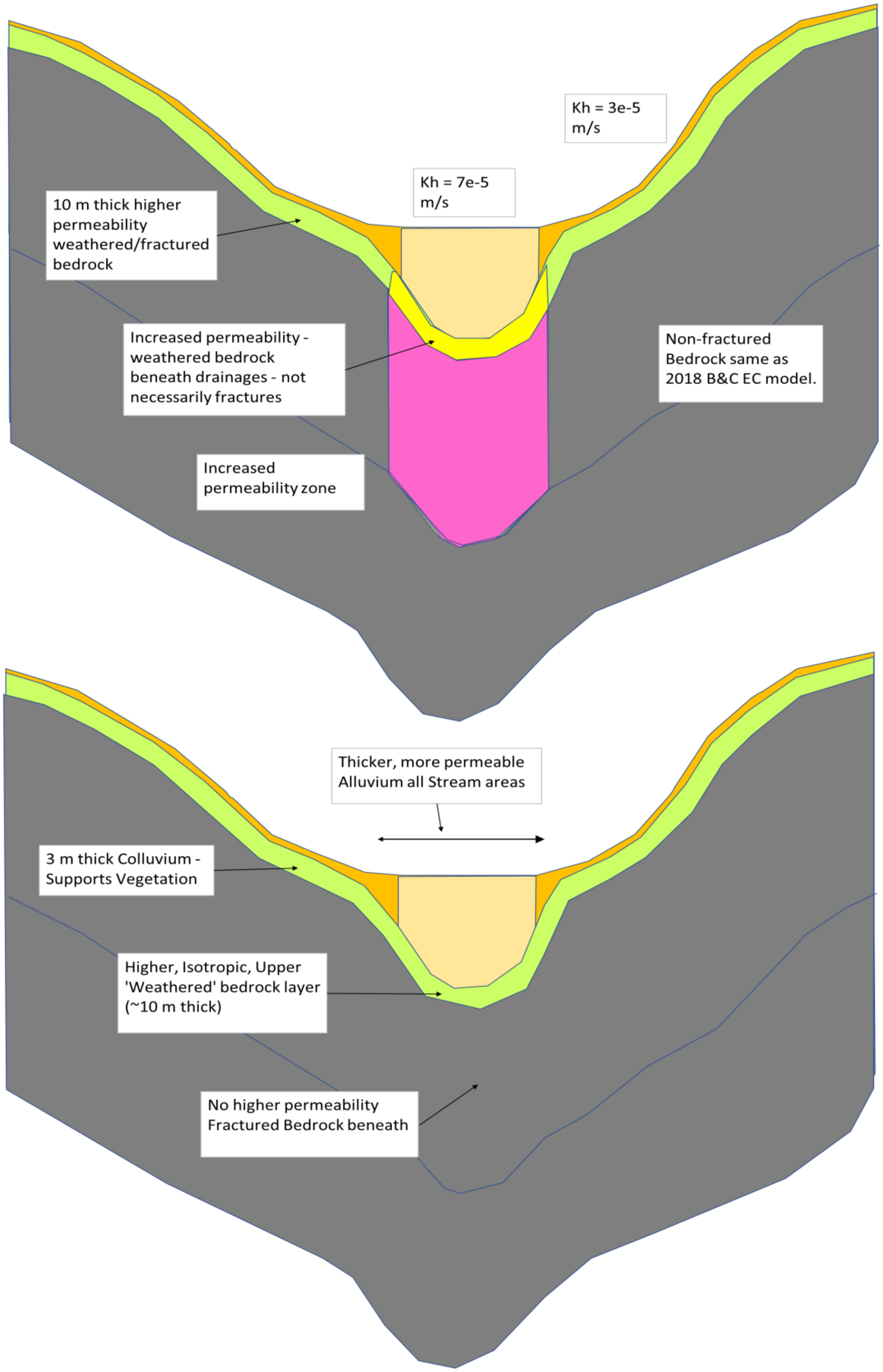


Figure 10. Upper Plot - 1st MIKESHE Model Configuration, Lower Plot - 2nd MIKESHE model Configuration with permeable fractured rock zone beneath streams removed.

### 5.1.6 Hourly Weather Data

Continuous NLDAS **hourly** precipitation, air temperature and potential evapotranspiration data from 2000 to 2020 were obtained for station (NLDAS Station X77-Y159), and spatially distributed based on elevation lapse rates of 15.3 %/100m for precipitation, and -1 C/100m (dry lapse rate) and -1.1 C/100m (wet lapse rate). These hourly data were used to drive the MIKESHE model, which actually determined timesteps on the order of every ½ hour, as the model adjusts to the variability of each weather dataset, and numerical calculations of each hydrologic process.

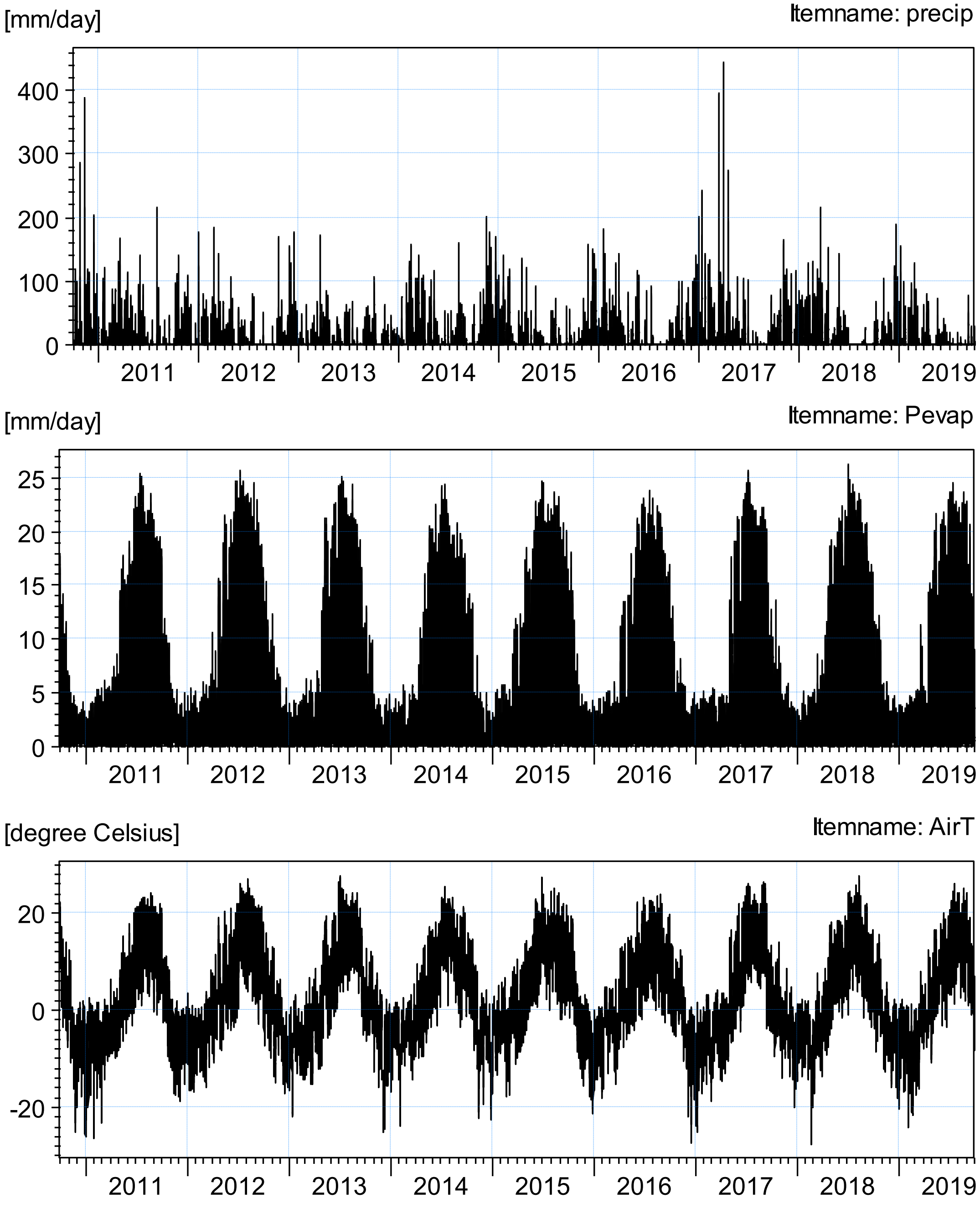


Figure 11. NLDAS Hourly Weather Data used to drive the MIKESHE model.

### 5.1.7 Snowmelt Parameters

The MIKESHE model uses a modified degree day method to calculate spatially-distributed (elevation), dynamic (daily) snow storage/melt over the model. Snowmelt is a critical process that drives the more significant seasonal groundwater and surface water dynamics. Specific inputs were determined mostly through calibration and include the following:

- Degree Day: 10 mm/C/d
- Melting temperature: -3 C
- Maximum wet snow fraction: 0.03
- Rain on snow thermal (0.5)

Snowmelt is a highly-sensitive modeling-process (and associated parameters) and strongly influences the ability to calibrate the entire annual surface/subsurface hydrologic system response. As such, the DEIS lack of local, spatially-variable snow course data over multiple years represents a significant data data gap, with large impacts on model calibration, and therefore predictive model uncertainty (or reliability).

### 5.1.8 Evapotranspiration Setup

USDA National Land Data Classification (NLDC) vegetation distributions (see Figure 13) defines the spatial distribution of vegetation in the MIKESHE model. So MIKESHE accounts for different types of vegetation, and their dynamic water consumption throughout the model domain, based on available water through the root zone and down to the water table, and on root depths and time-varying Leaf Area Index (LAI). The LAI time-series for each vegetation type indicated on Figure 12 were obtained from 8-day, 500-m resolution MODIS LAI datasets from 2010 to 2020. Differences in LAI values throughout each year are due mainly to seasonal variations in precipitation.

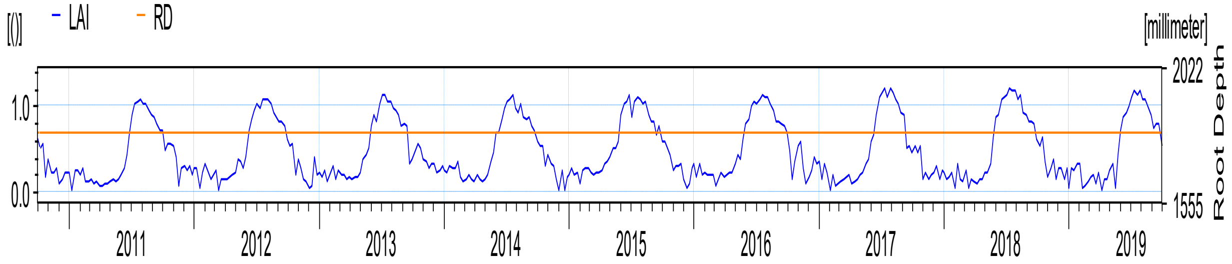


Figure 12. Example MODIS Satelite LAI time-series for NLDC Evergreen Forest Areas.

MIKESHE calculates and tracks 6 different types of evapotranspiration (including canopy interception, ponded evaporation, surface soil evaporation, sublimation, plant transpiration and saturated zone evapotranspiration), all of which add up to Actual Evapotranspiration (AET), which is always less than Potential Evapotranspiration (PET), due to water limitations at different times throughout the year. This is an important point because:

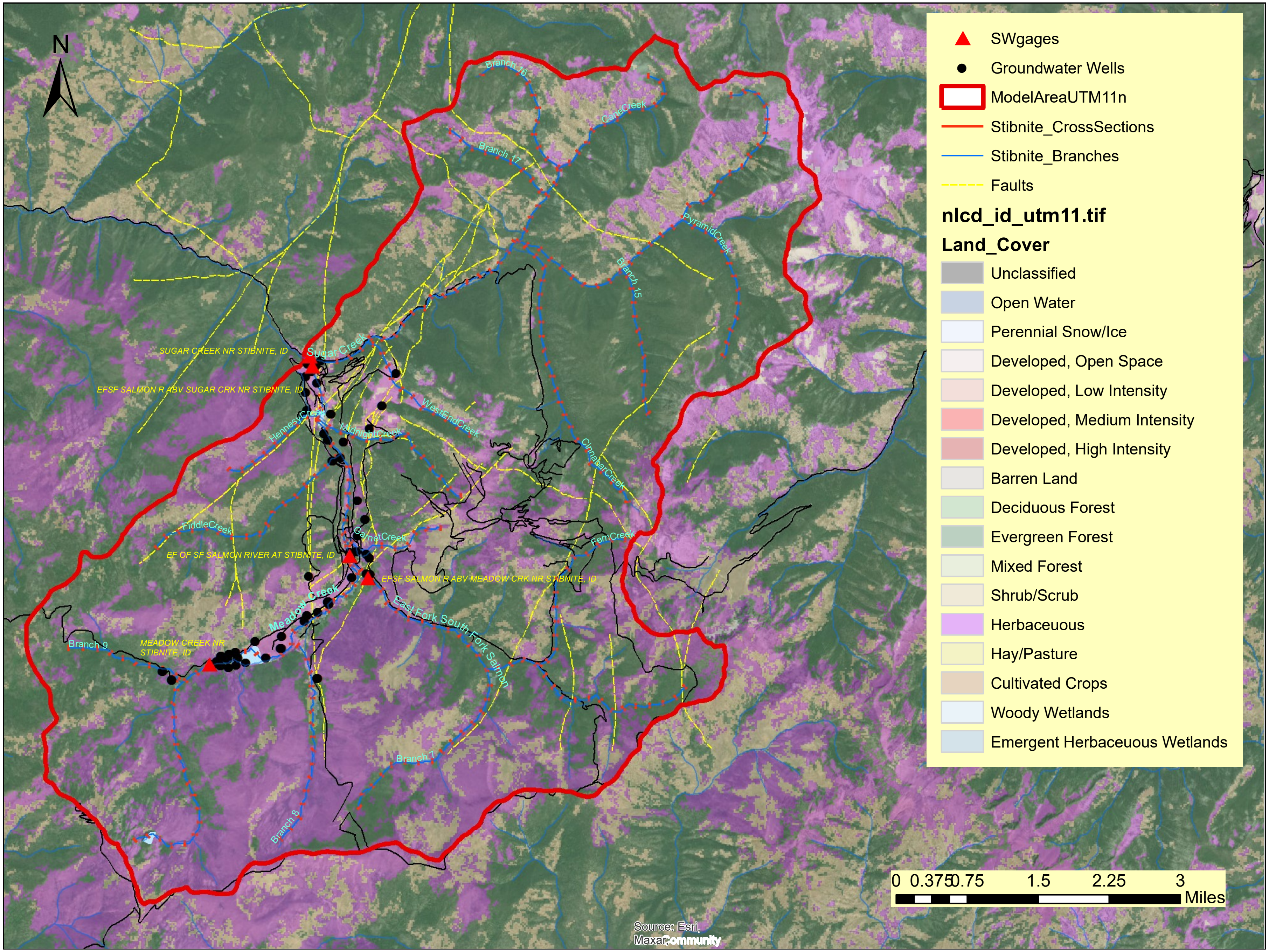


Figure 13. National Land Classification Dataset Vegetation Types

- the B&C 2018 Existing Conditions study incorrectly removes PET from available water supplied to recharge and runoff (they should have used AET), but AET is much more complex to calculate and depends on many factors, and
- Removing PET, effectively reduces estimates of recharge and runoff, which affect model calibration and subsequent predictions.

The MIKESHE model estimates HOURLY distributed AET each year, while MODFLOW doesn't.

### 5.1.9 Soil Distribution/Hydraulic Properties

No site soil database covering the entire model domain was provided in DEIS documents, so through calibration simulations, Loamy Sand unsaturated zone hydraulic properties were used to define the unsaturated zone.

### 5.1.10 Fully Hydrodynamic Hydraulic Network

A fully hydrodynamic hydraulic network was developed using DHI's MIKEHydro code, which is dynamically linked to the MIKESHE code. This is a key code capability of MIKESHE over the coupled meteoric water lumped-catchment spreadsheet with the Modflow-based SFR stream package. Applying external spreadsheet monthly estimates of runoff by a non-physically-based (i.e., using well known equations of flow) method to the Modflow SFR branches at specific points, by definition won't simulate the correct dynamic exchange of flow between surface water-aquifer, as this flow is dominated by the dynamic surface water stage, relative to the streambed, or underlying dynamic and spatially variable head. MIKESHE by contrast, calculates dynamic flows between surface water and groundwater at all points within the model, and at an hourly timestep. This permits detailed evaluation of mine impacts on the surrounding hydrologic system (i.e., how are peak storm flows or winter baseflows affected by mine dewatering, or post-closure flow through conditions).

Cross-sections, which represent calculation 'H' points (stage) in the MIKEHydro portion of the MIKESHE model were calculated every 200 meters using the mosaiced 10m topographic DEM, and extend ~100 m in most cases, unless local conditions dictated further adjustment.

This hydraulic stream network is then dynamically coupled to the underlying regular grid that defines overland flow, unsaturated and saturated flow, permitting interaction of the streamflow with lateral, fully-distributed overland surface water inflows, and fully-distributed interaction between surface water flows and underlying groundwater.

Though several choices exist on how to regulate the rate of flow between surface water and groundwater, via the streambed, the preliminary MIKESHE model assumes streamflow is entirely regulated by the hydraulic properties assigned to the uppermost alluvial aquifer. It makes no assumption on a reduced rate of flow (conductance), via a stream leakage coefficient.

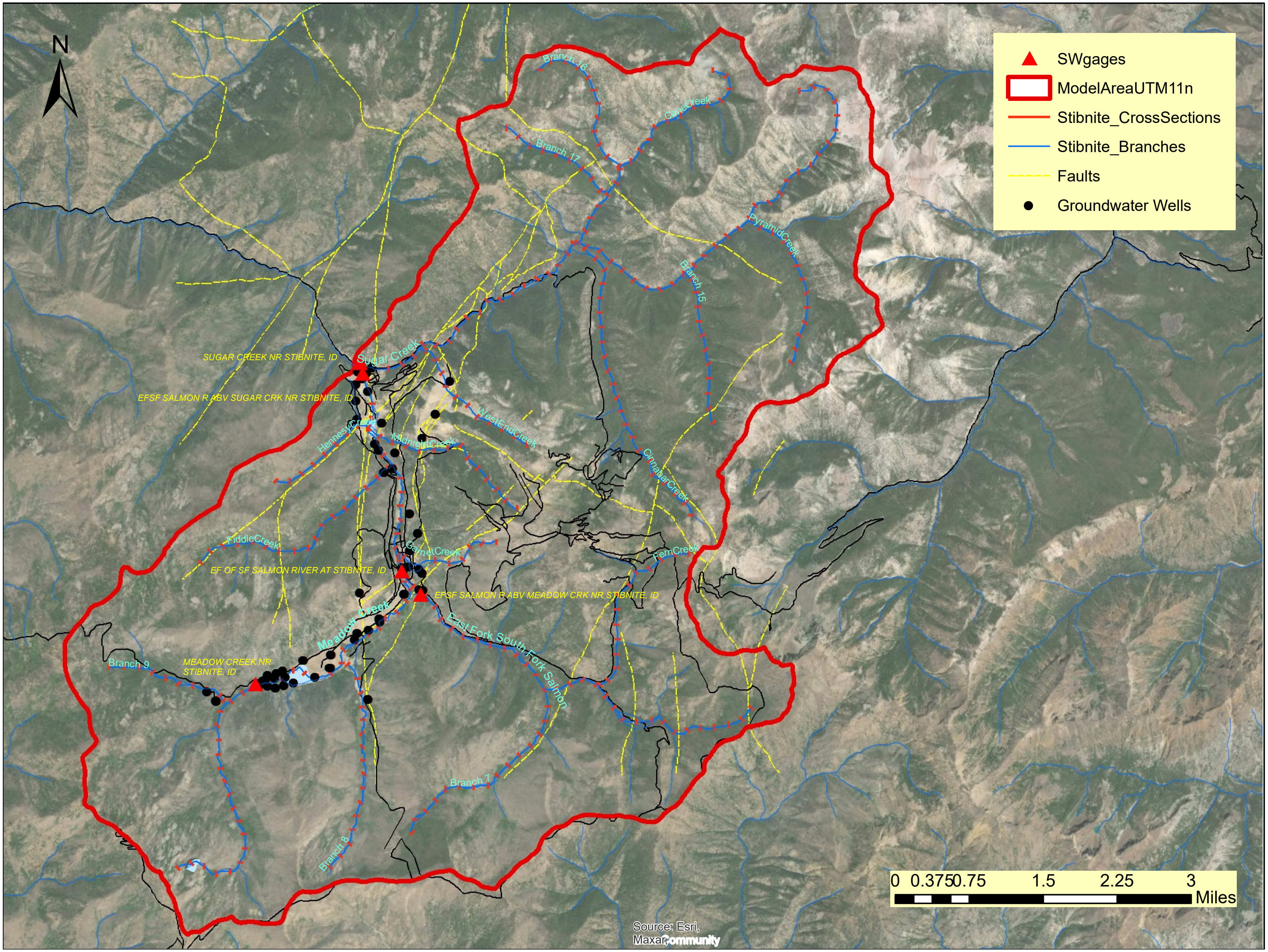


Figure 14. MIKESHE Model Boundary, Hydraulic Network and Cross-sections, Faults, Wells and Stream Gage Locations.

## 5.2 Calibration Response – Existing Conditions

Calibration results produced by the MIKESHE model are compared the B&C 2018 Existing Conditions model results to emphasize the following points:

- The MIKESHE calibration results are on an hourly/daily basis versus the monthly timestep in the B&C modeling effort, and therefore considered more robust/realistic,
- MIKESHE calibration includes comparison to more output types, thereby reducing non-uniqueness issues in the B&C modeling effort, and
- MIKESHE utilizes transient head data for calibration (App A, SPF, 2017 Groundwater Hydrology Baseline Study), while the B&C modeling apparently only used water levels from fall months (see B&C 2018 Existing Conditions, Section 2.3.2, P4), despite notable temporal variations (see B&C 2017 Water Resources Summary Report

**KEY POINT → the calibration here is more robust (hourly/daily transient calibration to more data) produces more unique/realistic solution and offers much greater insight into assessing short-term changes in hydrologic response (key to assessing) fish/habitat/wetland/ecosystem impacts.**

#### 5.2.1.1 Calibration to Available Groundwater Levels

Average mean errors of simulated MIKESHE head values compared to available 'Fall' period water levels (i.e., Table 2-1 in B&C 2018 EC study) are 0.12 m (positive under-simulates observed head), and -.35 m, 1.6 m and 2.5 m for mean error, layers 1 to 3, respectively. This compares well to Table 5-1 B&C 2018 EC model calibration (-1.9 ft for all layers, and 0.74 ft layer 1, and -6.5 ft, layer 2).

Calibrated results of the MIKESHE model also compare well to available measured transient well water level data (i.e., SPF 2017 Groundwater Hydrology Baseline Study, Appendix A – well summary, and Attachment A – hydrographs). Mean errors range from -0.2 m, -2.5 m, 13.6 m and 28 m, for layer 1 to 4, respectively (positive mean error = model under-simulates actual head at well). The greater error with depth, is due mostly to including calibration wells in the West End Pit area, apparently excluded from the B&C 2018 EC modeling, which likely specified permeabilities too high in this area. Figure 16 shows several simulated transient response (lines) against observed head fluctuations (dots), which compare well. Though the transient response is certainly not captured well at all wells, a much greater number of wells showed improved transient response for the conceptual configuration shown on the lower plot on Figure 10, where the deep (500') higher permeability fracture zone beneath all streams is removed, and storage terms adjusted to more appropriate values.

#### 5.2.1.2 Calibration to Available Surface Water Discharge

Figure 17 and Figure 18 compares hourly simulated and observed discharge at the Meadow Creek, East Fork of South Fork at Stibnite and Sugar Creek near Stibnite, and East Salmon above Sugar Creek gages from 10/1/2010 through 10/1/2019. For the conceptual model configuration similar to the B&C 2018 EC model (see upper plot on Figure 10) MIKESHE simulation results capture about 70% correlation to observed flows, while for the alternate conceptualization (lower plot on Figure 10) correlations captured close to 80% of discharge response, further suggesting the alternative conceptualization is more realistic than the B&C 2018 EC modeling configuration (i.e., 500' deeper permeable fracture zone beneath all streams).

Results of the simulated hourly hydraulic response (best seen on the 1-year simulated graphs shown on Figure 17 (center plot) and Figure 18 (lower plot)) are shown to capture much of the daily fluctuations important to a) understanding the dynamics of the existing system (i.e., to individual storm events throughout the year(s) and spring freshet), and b) more importantly to assessing the full range of impacts to the surrounding hydrologic system, which is simply unavailable to reviewers at a lumped monthly interval. Simulated monthly intervals misses a number ways in which the proposed mining would affect streamflows (i.e., changes in peak flow, baseflow, rising/falling limbs, total volumes etc)

Revisions to MIKESHE model inputs would improve the calibration of peak flows, but this modeling effort wasn't performed to calibrate at a high level, but rather to emphasize that integrated tools should have been considered for use in this DEIS, and alternative conceptualizations can lead to improved representation of available data not used in the B&C 2018 EC modeling effort.

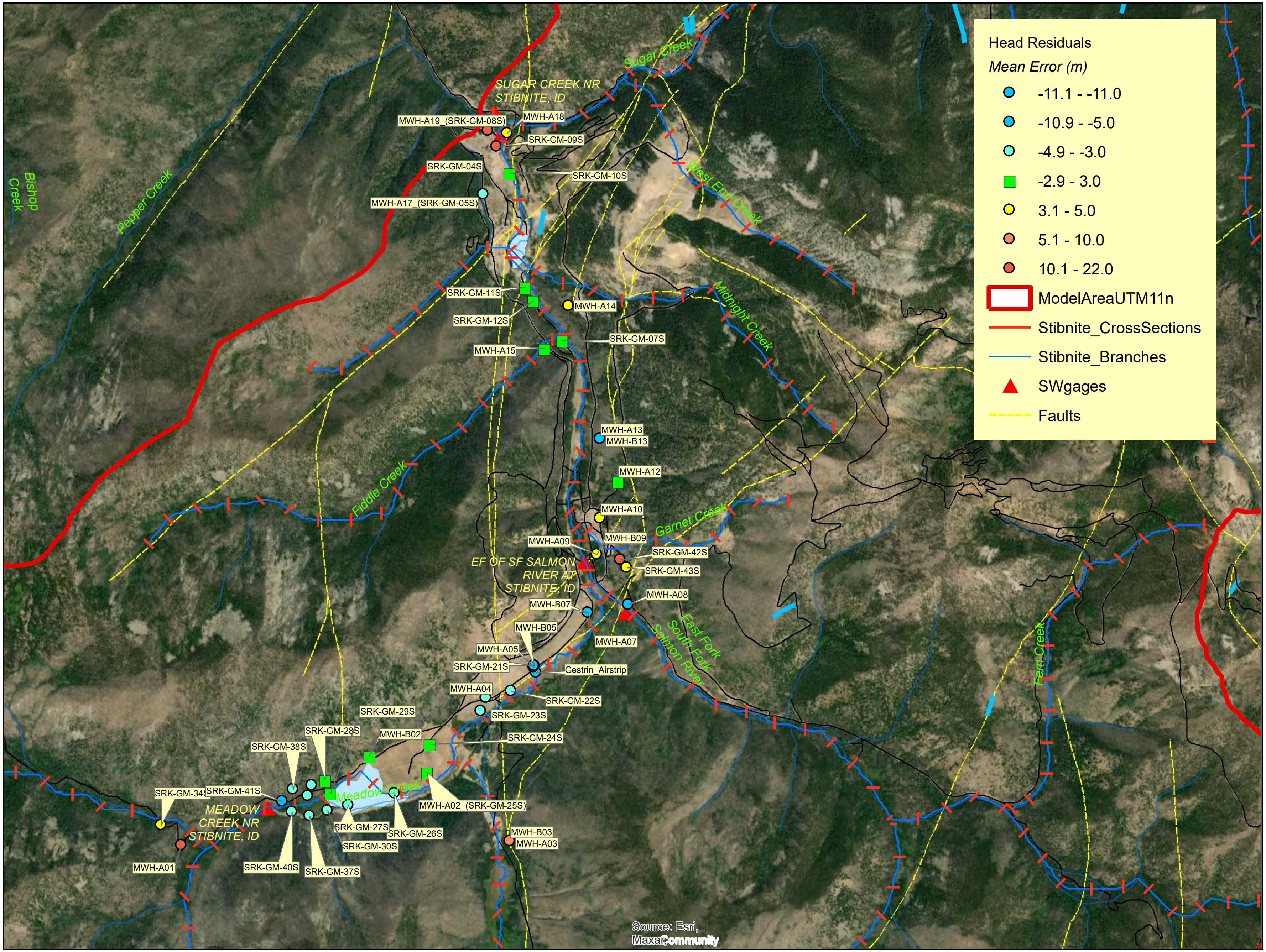
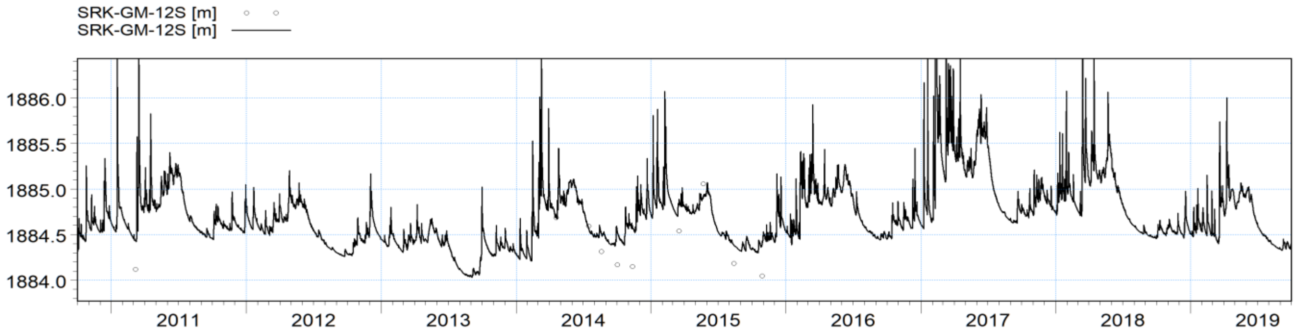
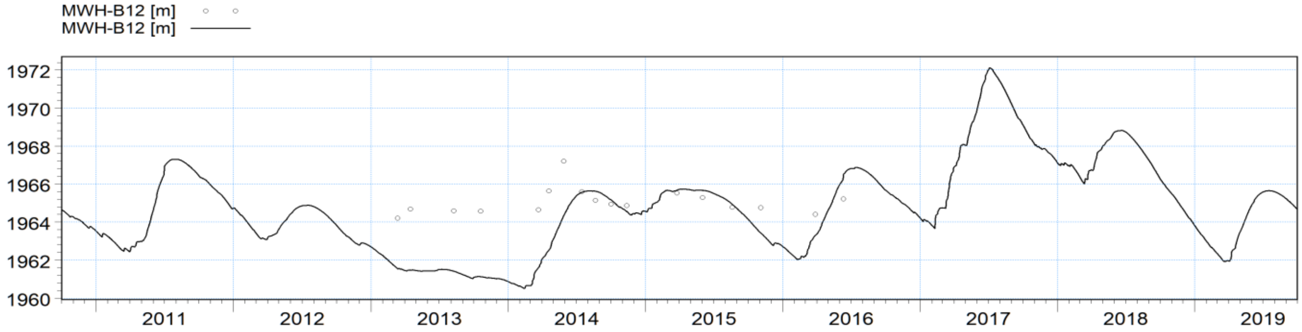


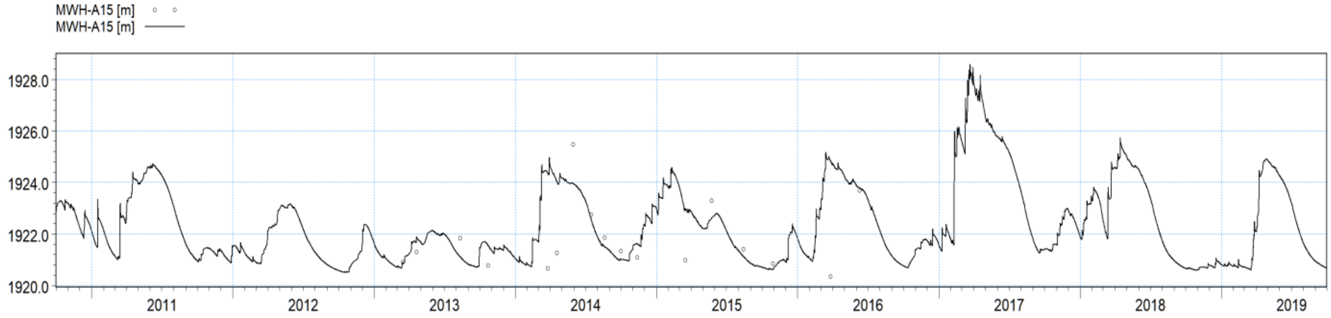
Figure 15. Simulated minus Observed Head Residuals – All Layers. Negative Mean Error (m) indicates model over-simulates head, positive means under-simulation.



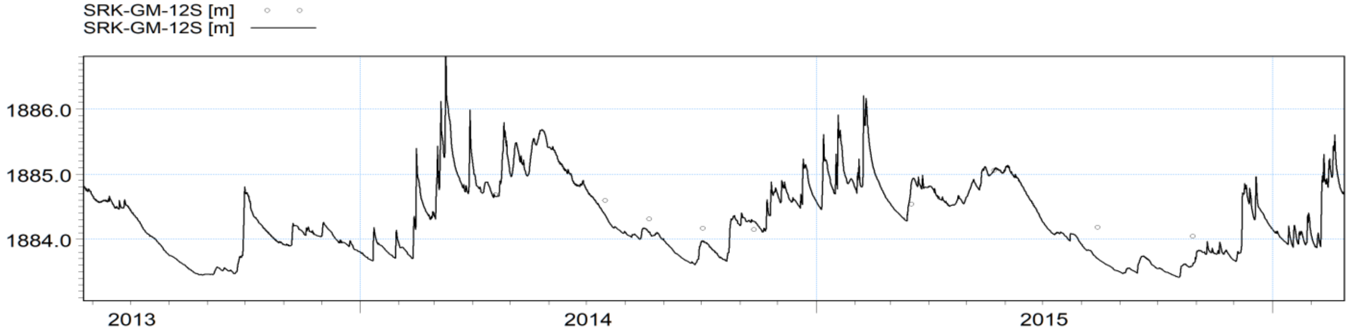
ME=-0.204604
MAE=0.23604
RMSE=0.272915



ME=1.27446
MAE=1.5914
RMSE=2.05996

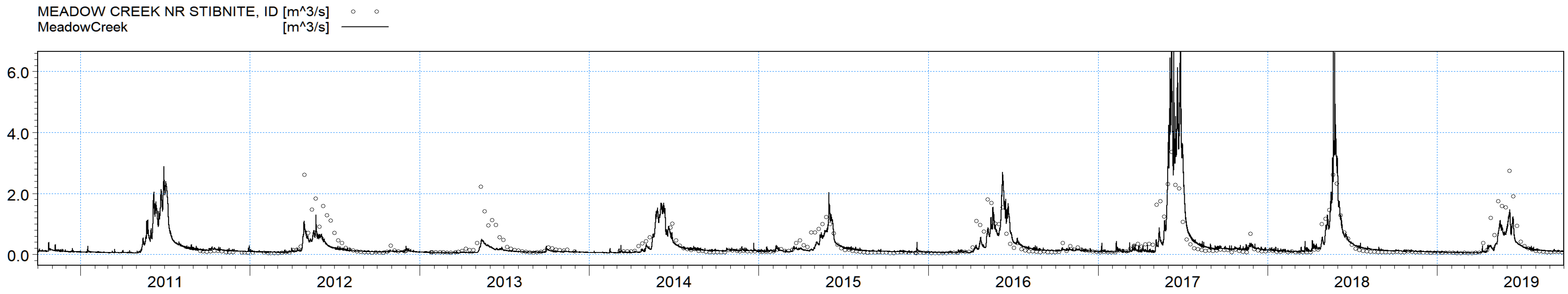


ME=-0.621275
MAE=1.1333
RMSE=1.7206

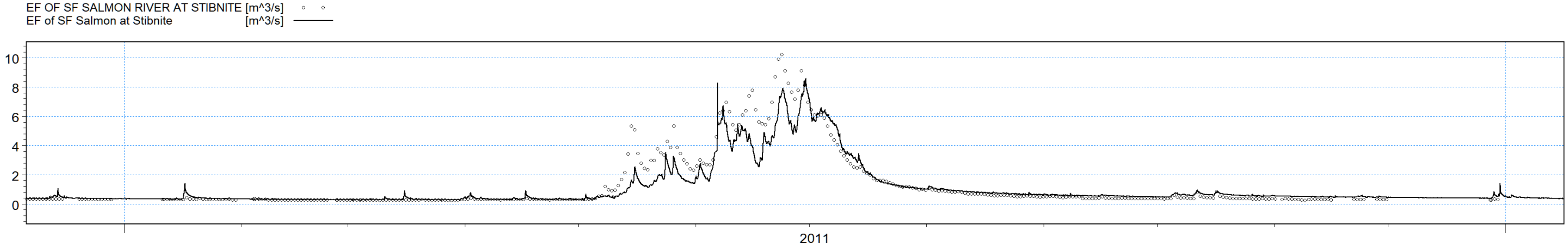


ME=0.143443
MAE=0.229954
RMSE=0.274036

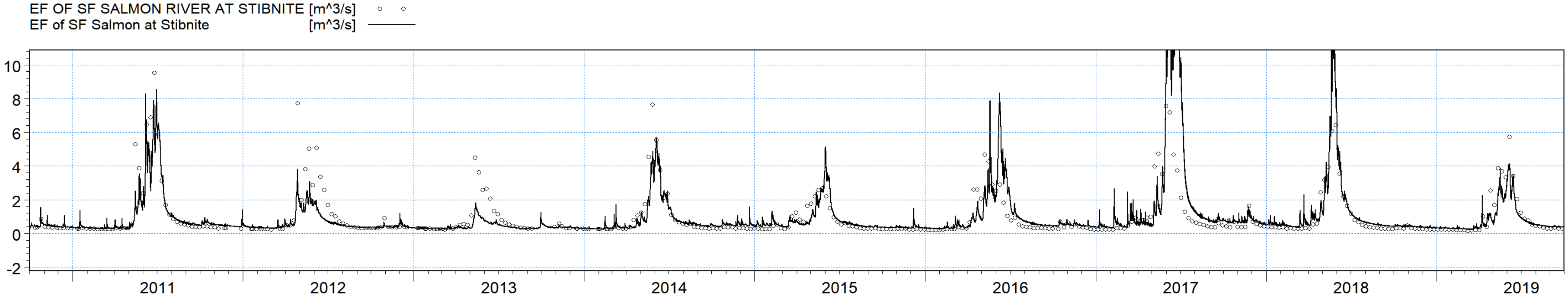
Figure 16. Simulated Daily Groundwater Levels (line) versus Observed Heads (dots) for select calibration wells. ME = Mean Error (m). Positive indicates model under simulates head.



ME=0.0678614
MAE=0.205031
RMSE=0.488846

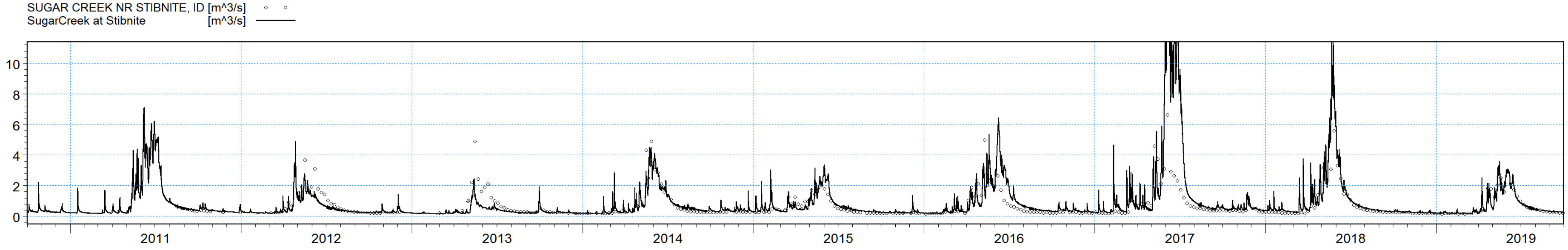


ME=-0.00825895
MAE=0.555935
RMSE=1.49564

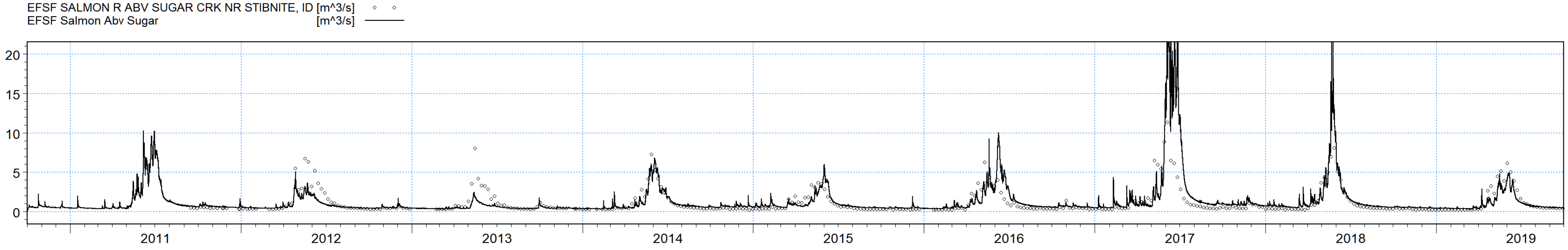


ME=-0.00825895
MAE=0.555935
RMSE=1.49564

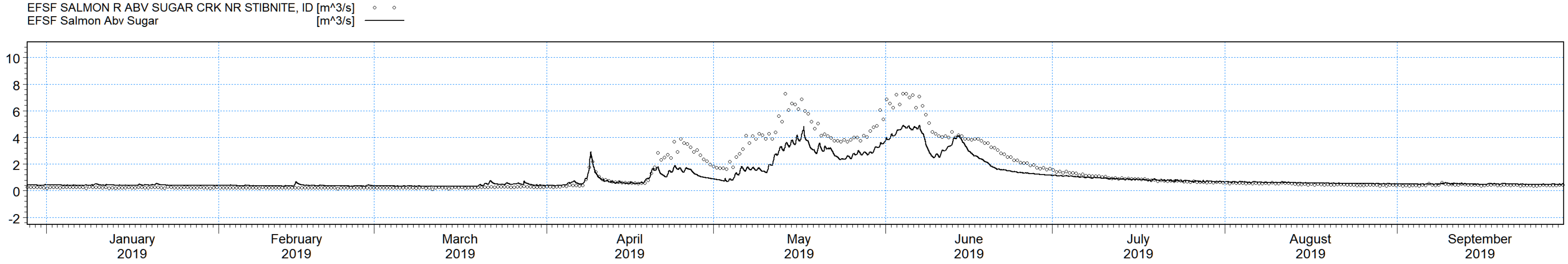
Figure 17. Simulated Stream Discharge (lines) Compared to Observed Gage Data (dots) for Meadow Creek Near Stibnite and EF of SF of Salmon River at Stibnite Gages.



ME=-0.193312
MAE=0.437598
RMSE=1.29464



ME=-0.0981647
MAE=0.667092
RMSE=1.75475



ME=-0.0981647
MAE=0.667092
RMSE=1.75475

Figure 18. Simulated Stream Discharge (lines) Compared to Observed Gage Discharge (dots) for EFSF Salmon River Above Sugar Creek and Sugar Creek Near Stibnite Gages.

### 5.2.1.3 Comparison of Available Water

A comparison of 'available water' in the B&C 2018 Existing Conditions study and MIKESHE estimates calculated by subtracting annual catchment actual evapotranspiration from precipitation is shown on Figure 19. Results show notable differences, attributed to a) differences in precipitation amounts/distribution, and b) MIKESHE's calculation of AET based on many distributed/dynamic variables versus removing PET + Sublimation.

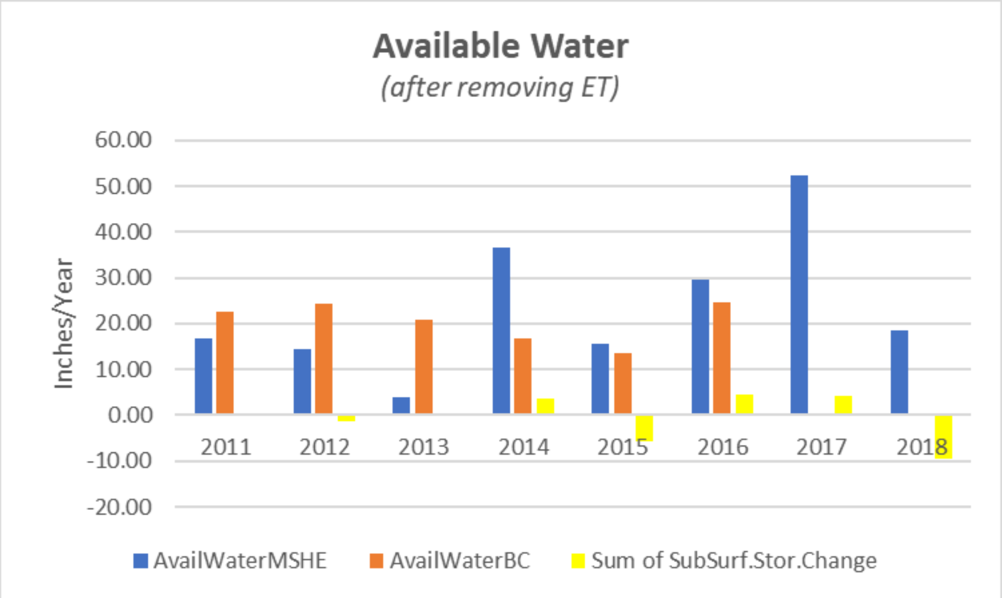


Figure 19. Comparison of Estimated 'Available Water' B&C 2018 Existing Conditions Study and MIKESHE simulation (Precipitation - ActualET).

### 5.2.1.4 Simulated Recharge

Figure 20 shows simulated average annual groundwater recharge from 10/1/2010 through 10/1/2019. The key point to showing this plot is to compare the physically-based/rigorous integrated model estimate against those estimated in the B&C 2018 Existing Conditions report. Recharge calculation is essential to realistically calculating the correct groundwater water balance and dynamics, but also surface runoff, both fundamental to correctly estimating the entire water balance and realistic/hydrologic response of the existing system and all predicted mine impacts.

Within most streambed areas, MIKESHE predicts net recharge is actually negative, where net Actual Evapotranspiration (AET) exceeds net recharge and represents areas of net water loss to the atmosphere. These are shown as negative-value blue-coloured cells on Figure 20, along drainages. Importantly, these results directly contradict the higher recharge assigned to valley floors in the B&C 2018 EC study. MIKESHE simulates an average recharge over the lower Valley Fill Recharge zone shown on the B&C 2018 Figure 3-2 as a net negative value (-3.7 in/yr), indicating AET exceeds any recharge in this zone. B&C estimate from 11.35 to 15.01 in/yr in the same area (after PET is removed). MIKESHE estimates about 23 in/yr for 'hillslope' areas, and about 21 in/yr for upper stream drainage areas, while B&C estimated from 2.88 to 4.10 in/yr for the same areas. **Importantly → MIKESHE recharge estimates differ dramatically by both zone and magnitude, strongly suggesting the B&C 2018 estimates are notably incorrect.**

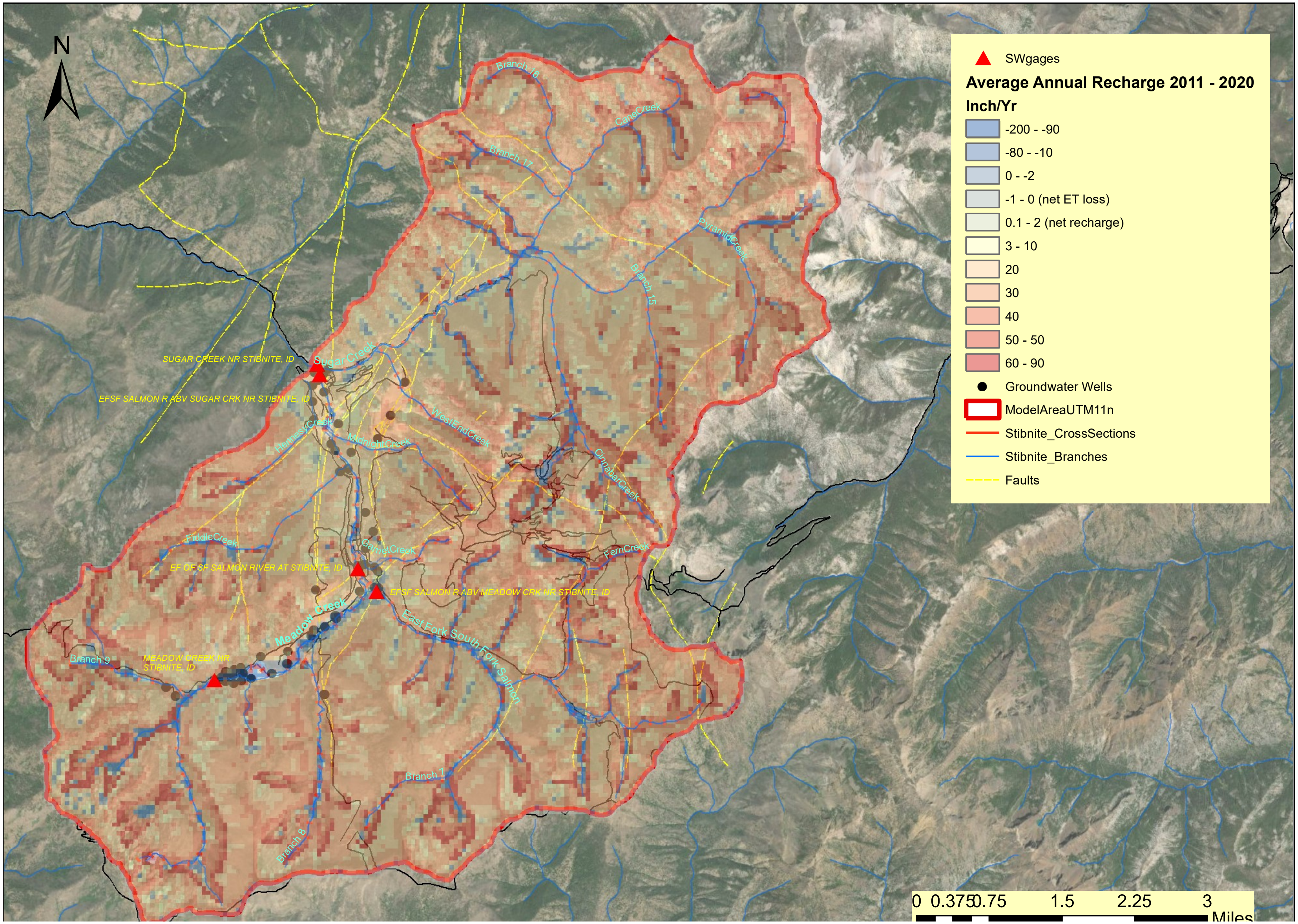
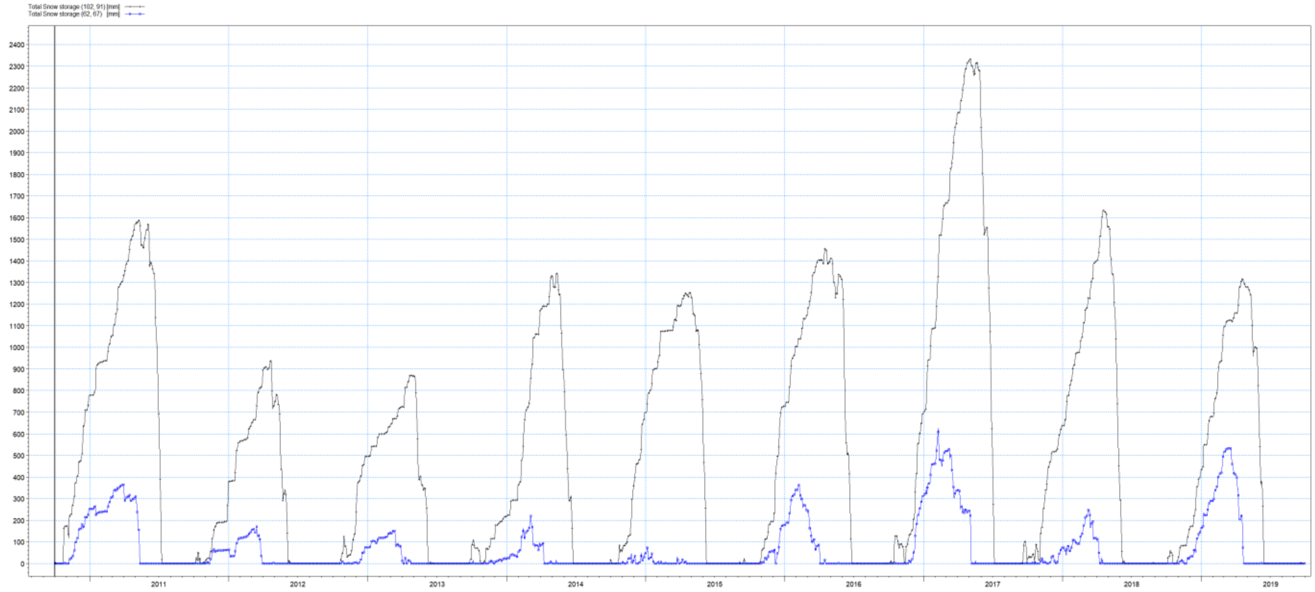
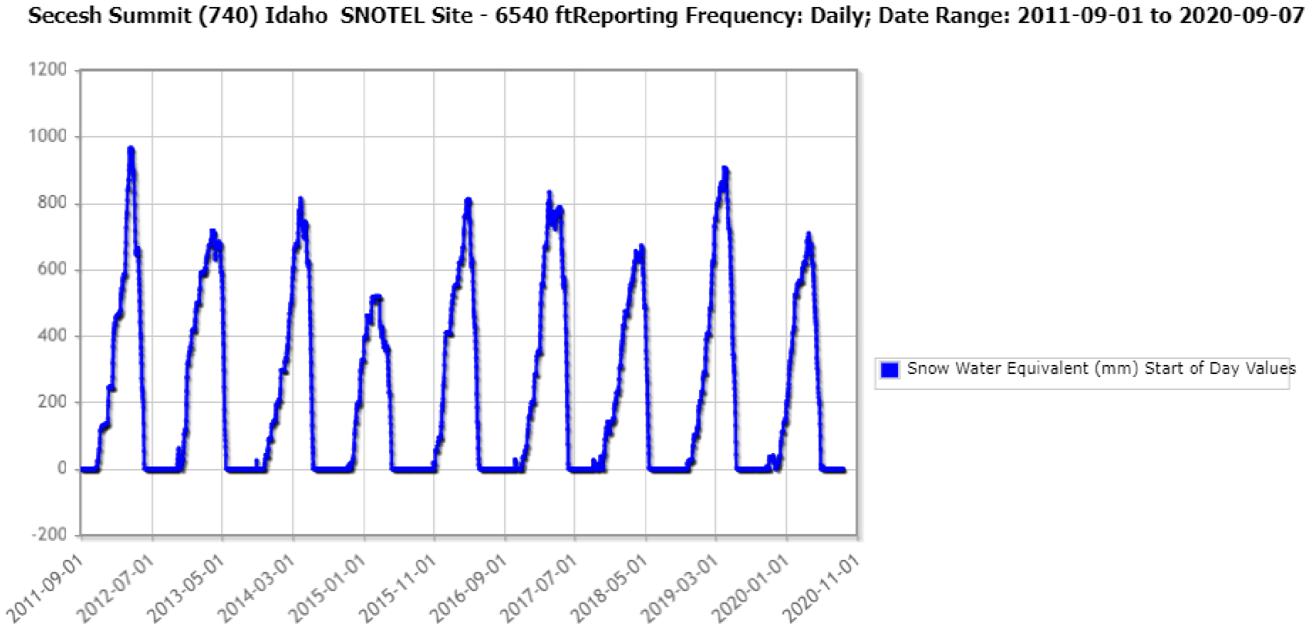


Figure 20. Simulated Average Annual Recharge (2011 to 2020)- Inches/Year. Negative values indicate net loss to ET Positive indicates net recharge to aquifer.

### 5.2.1.5 Simulated Snow Water Equivalent (SWE)

Figure 21 shows simulated SWE values (lower plot) at different elevations compare reasonably well against general SWE graphical characteristics (i.e., relatively fast melt off vs. slower rise) of two northern Idaho SNOTEL station SWE datasets[37] at different elevations, despite them being ~60 to ~150 km from the mine site and showing notable variation by location.





---

[37] https://www.wcc.nrcs.usda.gov/snow/snow_map.html

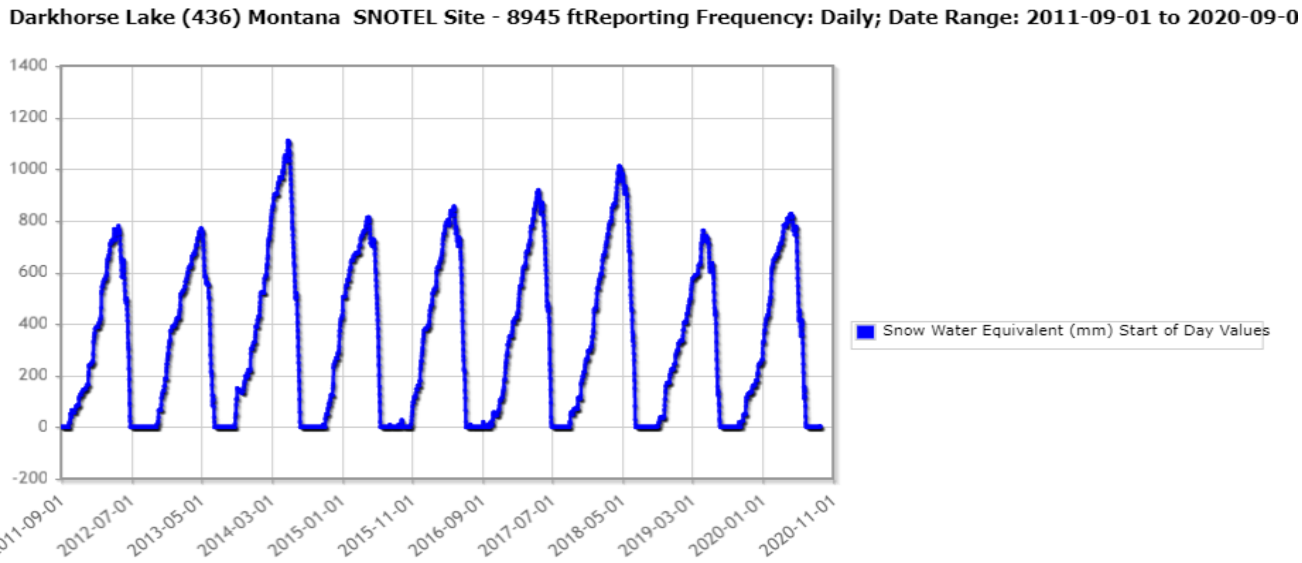


Figure 21. Comparison of simulated equivalent elevation SWE values (upper plot – blue line is SWE at ~6500’, while black line is SWE ~8500’) against observed SNOTEL SWE plots for Secesh Summit (6540 ft) and Darkhorse Lake (8945 ft), located 60 km and ~150 km from the mine site.

The lack of local snow course data provided in the DEIS documents at different elevations within the modelled area is a notable data gap, particularly because of the importance and sensitivity of simulated spatially-variable seasonal discharge and recharge dynamics to simulated spatial/temporal variability of SWE each year. Furthermore, the B&C 2018 Existing Conditions study failed to show SWE, or calibrate against these important data that drive much of the system hydrology. It’s important to note that the SWE varies substantially over the nearly 1000 m vertical elevation of the model catchment area.

#### 5.2.1.6 Gaining/Losing Estimate

Figure 22 compares simulated gaining/losing segments in MIKESHE versus observed data gaining/losing measurements from The B&C Water Resources Summary report, Figure 7-14, for the October 1-7, 2012 period. Results compare reasonably well, but should be refined through further calibration against seasonal variations in the gaining/losing stretches and magnitude at each location. These data are invaluable in calibrating important parameters governing the rate of flow between streams and underlying aquifer. Calibration of this parameter directly affects the predicted magnitude, extent and nature of impacts translated from pit dewatering, RIB infiltration and construction/operation of DRSF/TSF facilities. The B&C 2018 existing conditions modeling effort failed to utilize these available data, though limited in time/extent, to reduce the significant solution non-uniqueness, which translates into significant uncertainty in model predictions.

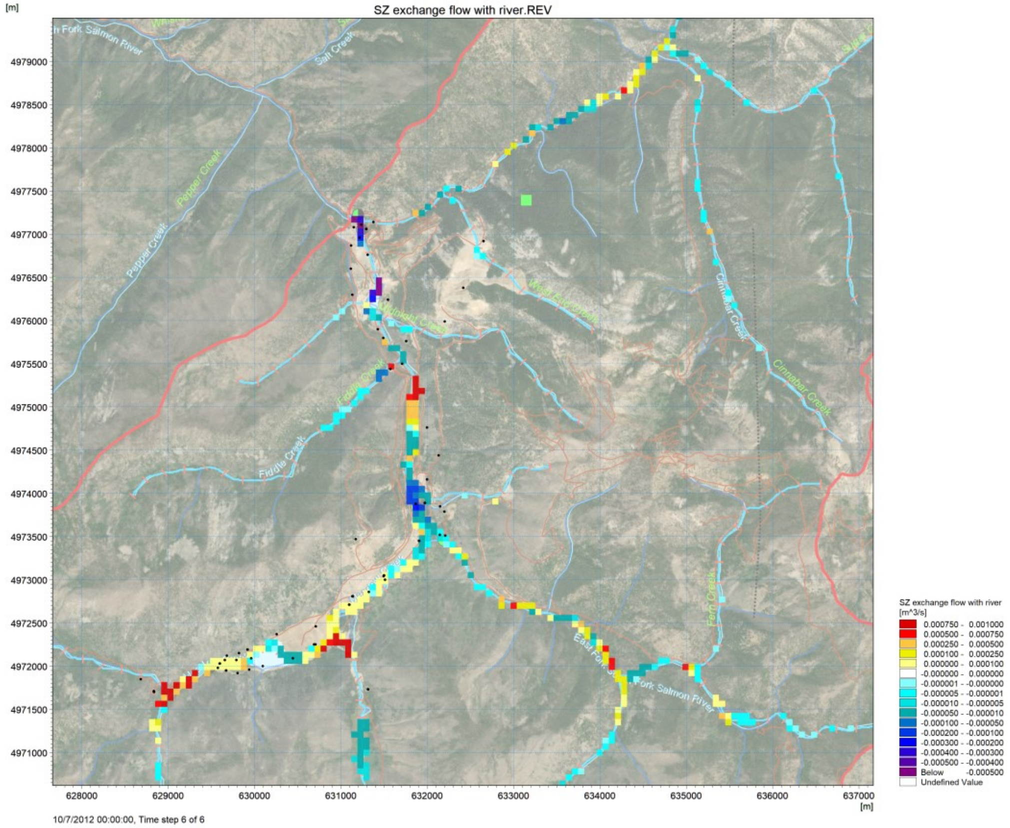
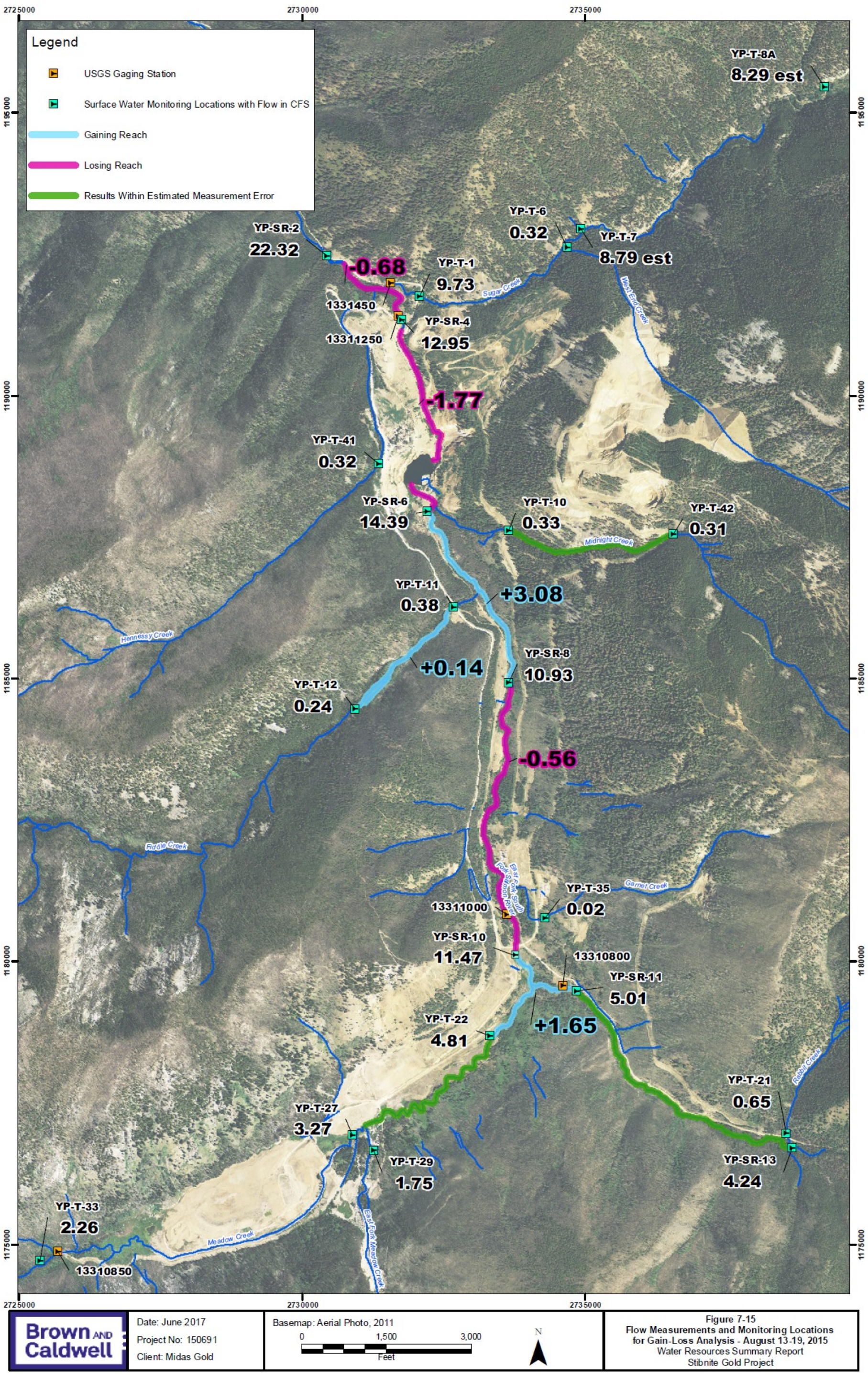


Figure 22. Simulated Gaining/Losing Stream Reaches. Red indicates gaining segments, while blue indicates losing (October 1-7, 2012 period similar to Figure 7-14 B&C 2017 Water Resources Summary Report to right).



Brown AND Caldwell

Date: June 2017

Project No: 150691

Client: Midas Gold

Basemap: Aerial Photo, 2011

0 1,500 3,000

Feet

**Figure 7-15**
**Flow Measurements and Monitoring Locations**
**for Gain-Loss Analysis - August 13-19, 2015**
Water Resources Summary Report
Stibnite Gold Project

### 5.2.1.7 Comparison of MIKESHE and B&C 2018 EC Model Surface Runoff Estimates

One of the main reasons for constructing the MIKESHE model was to assess key estimates of developed Results clearly show notable differences between what B&C 2018 modeling study assumed/estimated and what MIKESHE calculates, based on hourly, fully-coupled hydrologic conditions. Figure 23 clearly shows notable differences between simulated Valley Runoff and Hillslope Runoff, and strongly points to the need to utilize more complex tools, like physically-based integrated codes that dynamically couple surface water and groundwater and use distributed hourly climate as input to drive the hydrologic system. Importantly, results of MIKESHE show that runoff is actually much lower than direct recharge, leading to comparatively higher baseflow discharge to streams. These dynamics and comparatively low hillslope surface runoff contribution to catchment runoff (streamflow) are well known by hillslope hydrologists[38,39] .

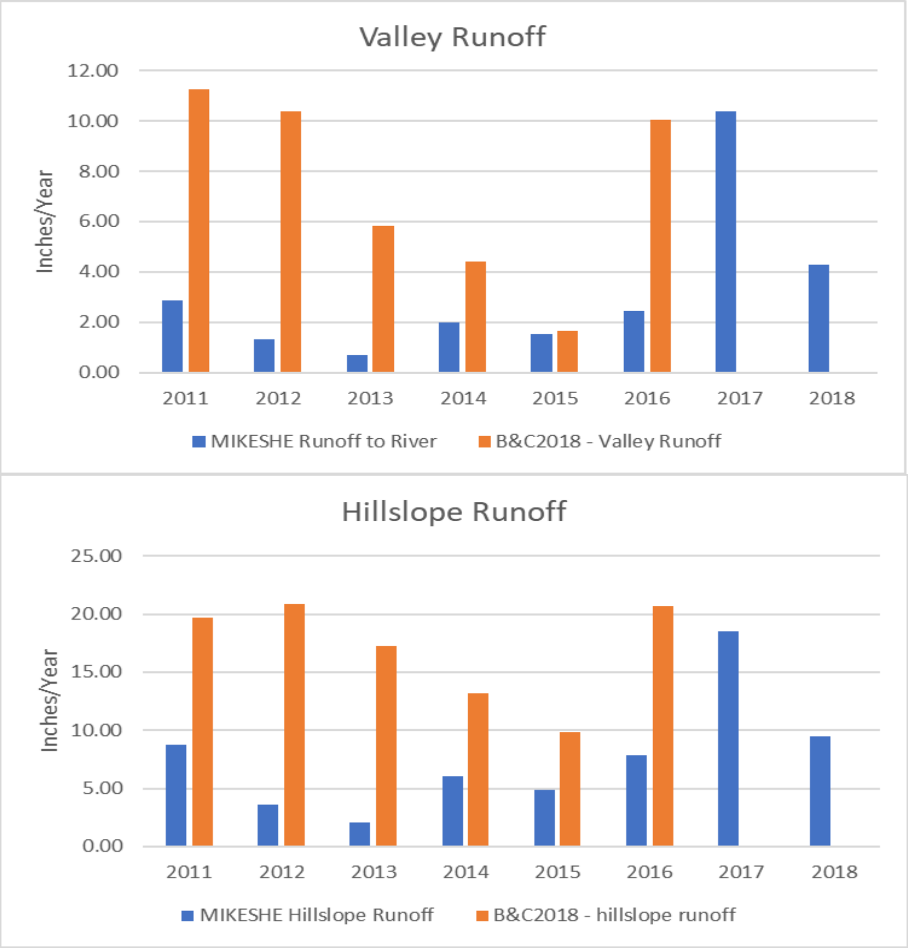


Figure 23. Comparison of MIKESHE and B&C 2018 Existing Conditions Model Runoff (Inches/Year)

---

[38] McGlynn, B. L., and J. J. McDonnell, Quantifying the relative contributions of riparian and hillslope zones to catchment runoff, Water Resour. Res., 39(11), 1310, doi:10.1029/2003WR002091, 2003.

[39] McDonnell, J.J., 2003. Where does water go when it rains? Moving beyond the variable source area concept of rainfall-runoff response. Hydrol. Process. 17, 1869–1875 (2003)

## 5.3 Year 2100 Climate Change Scenario – Existing Conditions

The baseline MIKESHE model was used to assess how future climate change would affect the existing conditions. Ideally, the climate change scenario here would have been applied to baseline and conditions following mine closure, but sufficient details of mine closure weren't provided in the DEIS and the review period/scope/budget were limited. Despite this, the evaluation of how existing conditions (10/1/2010 to 10/1/2019) change in Year 2100 give a good indication of how hydrologic conditions would change based on IPCC projections.

### 5.3.1 Year 2100 Climate Change Scenario Setup/Assumptions

The Year 2100 SRA2 CO2 Emission Scenario (IPCC – see www.ipcc.ch) climate change inputs were used to modify climate inputs for the Existing Conditions using DHI's MikeZero Climate Change Tool[40]. The SRA2 emissions scenario assumes a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines. All available global circulation models for the SRA2 scenario were selected for use including:

**Global Circulation Model**

BCM2
CNCM3
CSMK3
ECHOG
GFCM20
MPEH5
MRCGCM
GIER
NCPCM
HADCM3
INCM3
IPCM4
MPEH5
NCCCSM
MIMR
GFCM21
HADGEM

Monthly changes in precipitation, PET and air temperature used to modify the baseline spatially-distributed, hourly (NLDAS-based) weather inputs. Figure 24 shows the variation of these climate change factors by month. Significant adjustments are made to the air temperature, ranging from increases over 3 C in colder months, to near 6 C in summer months. Precipitation rates increase slightly from November through April (10 to 20%), but decrease in all other months, to nearly 60% in July. PET increases in all months by 1.2x to 1.5x, and over 2.0x in March and November. PET changes are calculated using a simple temperature-based method by Kay and Davies, 2008[41]

### 5.3.2 Comparison of Discharge for Baseline and Year 2100 Climate Change Conditions

Figure 25 shows simulated Baseline discharge at Meadow Creek gage compared to the Year 2100 Climate Change SRA2 Scenario at the same location. Similar to other climate change studies[12], notable changes occur in simulated discharge. For example, simulated climate change discharge increases throughout the warmer winter months (more evenly distributed), and the well-defined peak flow associated with present-day spring freshet are greatly diminished. Relative to baseline conditions, flows increase from 100% to over 1000% in winter months, and decline up to 100% during former peak freshet flows.

---

[40] http://manuals.mikepoweredbydhi.help/2017/General/ClimateChange_ScientificDoc.pdf

[41] Kay. A. L., Davies, H.N., 2008, Calculating potential evaporation from climate model data: A source of uncertainty for hydrological climate change impacts, Journal of Hydrology, 358, 221-239.

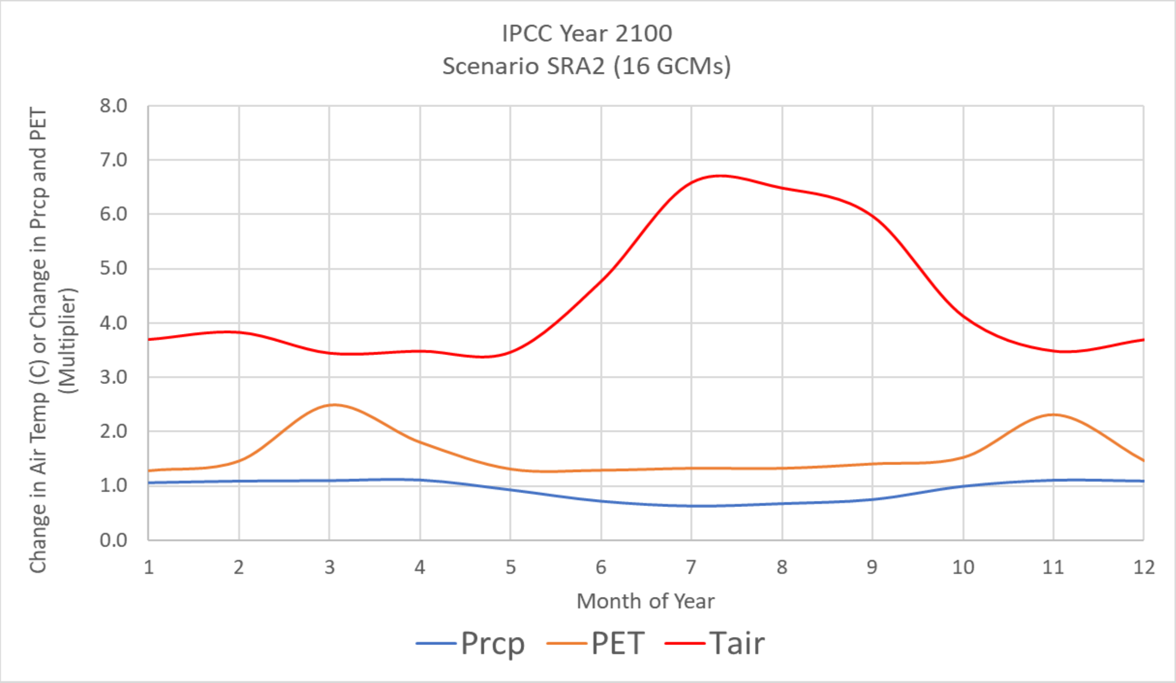


Figure 24. Estimated IPCC Monthly Change in Precipitation and PET (Multiplier factor) and Change in Air Temperature (degrees C) using the DHI Climate Change Software Tool for the specific Stibnite Mine latitude and longitude.

### 5.3.3 Comparison of Baseline and Year 2100 Climate Change Conditions

Figure 26 (upper plot) shows the annual percent change due to climate change in major water balance components. For example, AET increases 5 to more than 20% depending on the year, while both Valley and Hillslope Runoff decreases most years by 20 to 50%, and Baseflow from the River (i.e., streamflow loss) generally increases up to ~10% and baseflow to the river (gaining) ranges from -30% to positive 10% depending on the year. Precipitation across the model generally increase by 5%, though some years it can decrease (i.e., 2013) because of the amounts of precipitation in each season varies (and Figure 24 shows increase in precipitation some months, but declines in others. Though spatially quite variable average baseline recharge (2011 to 2020) across the model is ~20.3 in/yr, and climate change reduces this by about 2.5 in/yr.

**Importantly, the key point here is that climate change causes notable changes in the baseline hydrologic system and must be considered in assessing post-closure mine impacts to system hydrology to ensure final designs can accommodate both historical climate variability which is added to the historical variability**. In addition, stream temperature modeling should also account for not only changes in flows and stream stage, but also changes in predicted temperatures. DEIS Chapter 4 (Section 4.4.2.1.4.5) should have assessed local changes in flow and temperatures, especially in quantitative evaluation of alternatives (i.e., DEIS, Section 4.4.2.2.2.1), rather than relying on broad/unsupported assumptions or on the very regional/general impacts of climate change reported in Halofsky et al, 2018[42].

---

[42] Halofsky, J. E., D. L. Peterson, J. J. Ho, N. J. Little, and L. A. Joyce, editors 2018 Climate change vulnerability and adaptation in the Intermountain Region. Gen. Tech. Rep. RMRS-GTR-375. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Part 1. pp. 1–197.

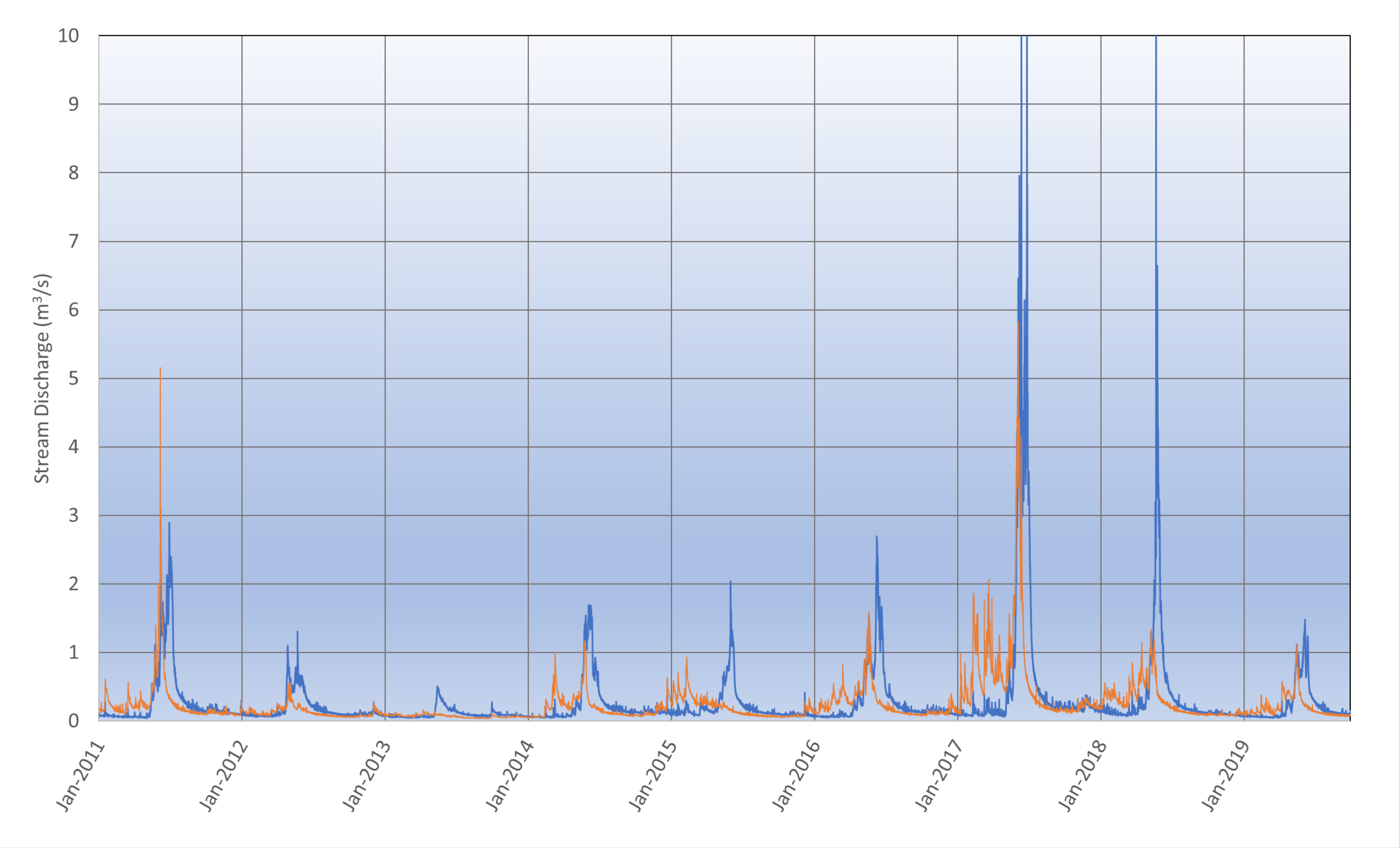


Figure 25. Simulated Baseline (blue line) and Climate Change (orange line) Discharge at Meadow Creek Gage (m3/s)

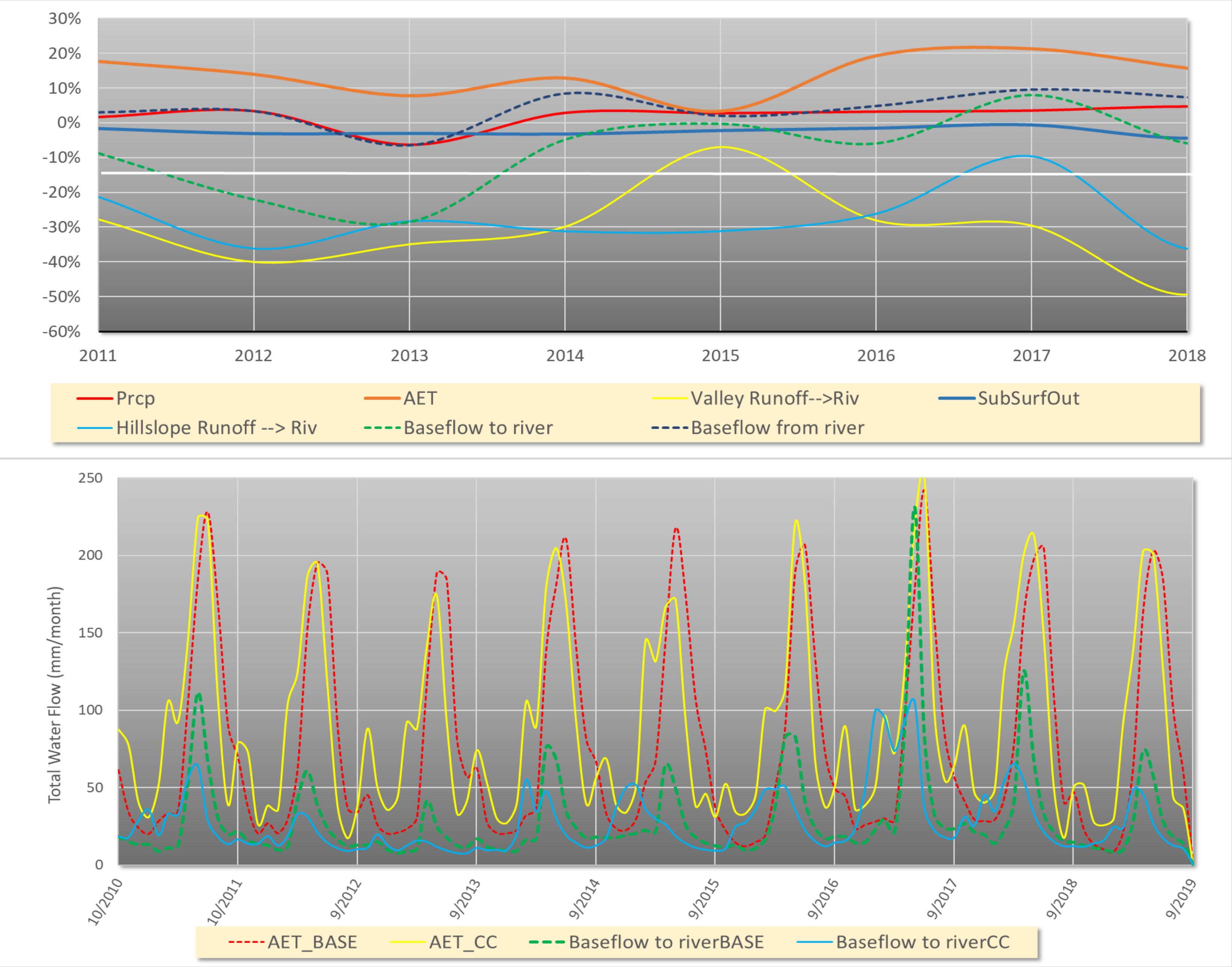


Figure 26. Annual Simulated Percent Change (Relative to Baseflow) in Water Balance Components due to Climate Change (upper plot) and Monthly Baseline and Climate change Water Balance for AET and Baseflow to River.