The retrieval of meaningful results from the validation activity, however, relies on recognition of the assumptions made when comparing the two dissimilar observations. For example, careful consideration must be made of the disparate spatial scales, biased geographic distribution, and temporal differences of the observations. Drawing on experience achieved through statistical and iterative analyses, the SSPO employs validation methods that both account for, and reduce error introduced by, these dissimilarities whenever possible [*McClain et al.*, 2000]. As an example, rather than compare a single satellite pixel with a coincident in situ observation, sensitivity studies suggest the that use of a 5 x 5 pixel box adds confidence to the satellite retrieval while limiting inaccuracy posed by geophysical variability at the observation site and navigation, sensor, and algorithm errors in the satellite observations [*Hu et al.*, 2001].

The routines developed by the SSPO are satellite-independent and are currently used to operationally validate both SeaWiFS and MODIS Terra level-2 data products. Although not addressed specifically in this article, comparable analyses are executed regularly for other U.S. and international satellite-borne ocean color instruments. The data included in Figure 1 and Table 1 are valid as of February 2003. These results are updated regularly and posted publicly online as new validation data are acquired and submitted to SeaBASS.

Data Availability

The SeaBASS Web site (http://seabass.gsfc.nasa.gov) provides a complete description of the system architecture, comprehensive documentation on policies and protocols, and direct access to the bio-optical data set and validation results. Briefly, the architecture of SeaBASS consists of three tiers: (1) geophysical data and metadata recorded in digital text files that adhere to ASCII format; (2) a directory tree structure residing on a dedicated server at the NASA Goddard Space Flight Center for storage of the data files; and (3) a relational database management system (RDBMS), built using the SQL Server product from Sybase, Inc., used to catalog and distribute the data and files. Through the use of online search engines that interface with the RDBMS, the full bio-optical data set is queriable and available to authorized users via the Internet. The impetus for this design was easy data access, including online access, with sufficient security to limit usage when necessary, all while accommodating a variety of computer operating systems. In addition, SeaBASS was built to be expandable and flexible enough to accommodate large data sets and multiple data types.

All data collected prior to 31 December 1999 are fully available to the general public. To protect the publication rights of contributors, access to more recent data is limited to SIMBIOS Science Team members (current NRA), NASA-funded researchers, and regular voluntary contributors, as defined by the current SeaBASS access policy. Other investigators are able to query for generic information about these restricted data, but will be referred to the contributors for access to the data itself. Upon the conclusion of each SIMBIOS NRA, restricted data collected under that NRA are made publicly available. These public data are also released to the National Oceanic and Atmospheric Administration's (NOAA) National Oceanographic Data Center (NODC) for inclusion in their archive.

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Abandoned Mines, Mountain Sports, and Climate Variability: Implications for the Colorado Tourism Economy

PAGES 377, 386

Until recently, the allure of the mountains in the American West was primarily extractive, for commodities like timber, water, and precious metals [*Baron et. al.*, 2000]. Now, the effective marketing and management of the region's "white gold" by the ski industry has stimulated significant recreation-related growth and development in the last several decades. Under an uncertain climatic future, however, these burgeoning industries, and the communities that have grown up in relation to them, are facing water quality constraints inherited from historical mining practices, causing mountain water to become a limited resource more valuable than the precious metals of the past. Further, the current lack of proven, in-situ approaches for addressing distributed, mining waste pollution of fresh water complicates potential remediation efforts.

In addition, the recent severe drought in Colorado has highlighted the importance of high mountain water sources to economic well-being in the Western United States. When coupled with rapidly growing mountain development and the environmental legacies of historical hard rock mining, fears of insufficient quantities of precipitation have renewed

By Andrew Todd, Diane McKnight, and Lane Wyatt

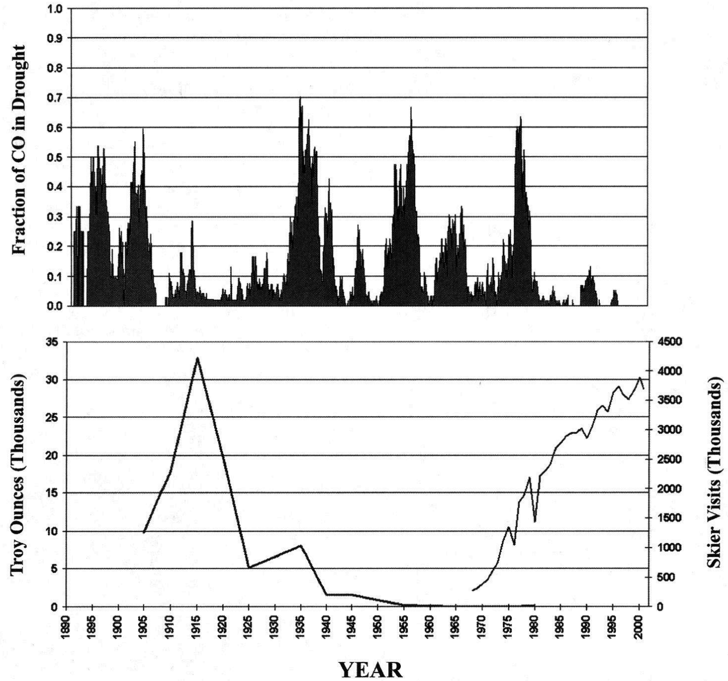

*Fig. 1. (a) Fraction of Colorado in drought based on 48 Month SPI, data ending in 1996 [*McKee, *2000]; (b) Historical recovered gold production in Summit County, Colorado (data obtained from U.S. Department of the Interior, 1905–1980) and historical number of skier visits in Summit County, Colorado ("Colorado Ski Country, 2003," University of Colorado, unpublished data, 2003).*

concern about alpine water issues. As evidence of the expansion of population in mountain areas, according to the U.S. Census Bureau, the population of Summit County, Colorado nearly doubled (82.8%) between 1990 and 2000. The evolving situation within the Snake River Basin of Summit County provides a case study of this growing interaction between the old and the new in the headwaters of Western, mountain watersheds.

Acid Rock Drainage Effects on Water Quality in Alpine Areas

The release of acidic, metal-enriched water from abandoned mines and associated mining wastes, referred to as acid rock drainage (ARD), is an environmental legacy that degrades water quality and limits economic development in Colorado. Excavation of veins of precious minerals exposes sulfidic minerals (predominantly pyrite) to oxygen. This makes possible chemical reactions mediated by the iron-oxidizing bacterium *Thiobacillus ferrooxidans* and other acidophiles, ultimately lowering pH. Due to resultant acidic conditions, this weathering increases the mobilization of metals (e.g., Zn, Cd, and Pb) within sulfide-containing minerals, as well as trace metals (e.g., Al, Mn) from other minerals in the country rock [*McKnight and Bencala*, 1990]. In-stream consequences include precipitation of iron, aluminum, and manganese oxides on the stream bed, and increased dissolved trace metal and sulfate concentrations.

Due to copious quantities of mine waste rock and the slow biogeochemical process of ARD generation, this pollution can continue to flow long after the mining ends. With more than 7,000 abandoned mines in Colorado, high metal ion concentrations, low pH, and oxide deposition constrain the habitat suitability and resultant diversity of stream biota, including fish, invertebrates, algae, and microbes, for more than 1,600 miles of streams [*Rueth et. al.*, 2002]. Unfortunately, ARD-related water quality problems are not unique to Colorado, nor the American West. The U.S. Bureau of Mines reports mine contamination affecting more than 12,000 miles of rivers and streams and 180,000 acres of lakes nationwide. ARD has been referred to as the greatest water quality problem facing the Western United States [*Mineral Policy Center*, 1997].

The legacy of prospecting for precious metals that fueled historical mining efforts in the West (Figure 1) continues to affect water quality, overshadowing the water quality impacts associated with the larger-scale, modern Western mining facilities for such commodities as molybdenum and gravel. The impacts of extractive industrial activity conflict with the other major economic driver in the Colorado Rockies: tourism. In Colorado, the tourism industry is driven primarily by the ski resorts and associated infrastructure. The annual migration of skiers from around the world to the slopes of Colorado's major ski resorts is motivated by the crisp mountain air, breathtaking scenery, and champagne powder. To meet the demand for accessibility, ample terrain, and lengthy seasons, resort operators have relied on the natural resources of forest land for expansions and river water for artificial snow-making.

The drive along I-70, the major highway that takes skiers from Denver to several mountain ski resorts (including Summit County's Breckenridge, Copper Mountain, Keystone, and Arapahoe Basin), reveals the magnitude of past mining activities. The roadside hamlet of Silver Plume was named for the white streaks of silver that appeared in the rocks, and the name of the town of Frisco is a reference to San Francisco, birthplace of the gold rush. The mountains and hills surrounding I-70 are riddled with brilliant orange tailings piles and weathered mine structures, and trail names at ski resorts (e.g., Keystone Mountain's Mine Shaft, Sluice Box, and Prospector) reflect the region's mining history.

For managers at several Summit County resorts, this intersection of the mining and recreational industries has become more than an exercise in trail naming in recent years. Chemical contamination of surface waters by ARD has threatened to hold down the use of stream water for snow-making. For example, application of ARD-contaminated Snake River water to ski runs through snow-making has been evaluated as a mechanism for spreading metal contamination into unimpacted drainages [*Hydrosphere*, 2001]. Within the same watershed, Arapahoe Basin Ski Area has addressed the challenge of responsibly developing snow-making capabilities utilizing uncontaminated water from the Snake River's North Fork, a sizable tributary which dilutes the waters of the mainstem as it enters the Keystone resort community.

The Snake River: A Case Study for ARD and Snow-making Interactions

The Snake River Watershed in Summit County is affected by ARD of both natural and anthropogenic sources. The headwaters of the Upper Snake River drain a watershed with pyrite disseminated throughout the country rock, adding acidity and dissolved metals to the stream before running through a naturally occurring iron bog [*Theobald et. al.*, 1963]. Numerous abandoned mines are scattered throughout the Peru Creek watershed, one of the Snake River's primary tributaries. The Pennsylvania Mine, a prolific producer of Summit County silver into the mid-1940s, is estimated to be one of the largest sources of aqueous metals and acidity [*McKnight and Bencala*, 1990]. Significant stretches of the Snake River and Peru Creek are coated with iron and aluminum oxides that precipitate when mixed with inflow from pristine tributaries, a chemical reaction resulting from the increase in the pH of the stream water. In some stream reaches with high concentrations

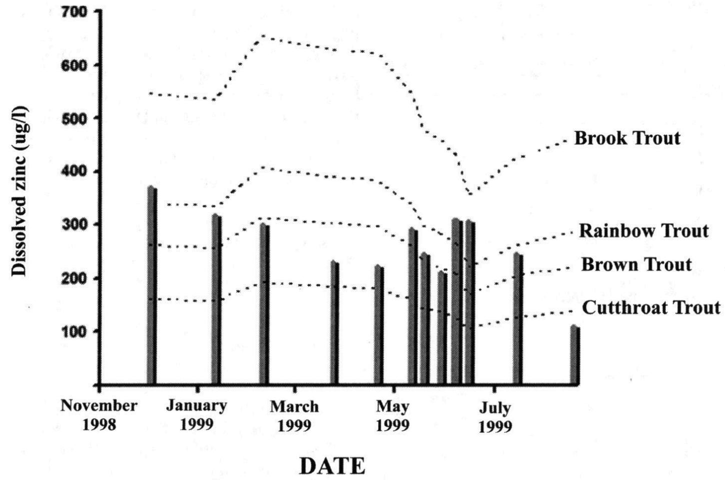

*Fig. 2. Aqueous zinc concentrations and calculated acute toxicity thresholds in the Snake River near the Keystone snow-making intake [*Hydrosphere Resource Consultants, *1999]. Acute toxicity thresholds are a function of water hardness and were calculated using species-specific proposed standard formulae (Animas River Stakeholders Group, Animas River Use Attainability Analysis, unpublished data, 1999).*

of zinc, cadmium, copper, lead, and manganese, the impact is so severe that both the Snake River and Peru Creek are identified on Colorado's 1998 303(d) list of impaired water bodies.

Snow-making at the Keystone Ski Area and the Snake River

In a very direct manner, the downstream water chemistry consequences of ARD have created a difficult management situation for one of Summit County's most popular ski resorts. The ARD-polluted mainstem of the Snake River flows through the resort community of Keystone. Although Keystone Resort has been making snow with Snake River water since 1971, the detection of heavy metals in previously pristine mountain drainages, coupled with the resort's desire to increase its snow-making water diversion from 550 to 1,350 acre-feet, has raised concerns of the potential for spreading the pollution through snow-making [*Hydrosphere,* 2001].

At the snow-making water diversion, in-stream concentrations of zinc exceed aquatic life criteria, and concentrations of dissolved cadmium and copper occasionally exceed water quality criteria for aquatic life (~1.5 and 5 ppb, respectively, at a hardness of 50 mg/l) [*Hydrosphere,* 2001]. Figure 2 illustrates the acute toxicity of aqueous zinc concentrations measured at the snow-making intake to four fish species that are commonly found in streams in Colorado. For all but the brook trout, aqueous zinc levels regularly exceed acute toxicity thresholds.

Through the process of snow-making, these contaminated waters are broadcast over large slope areas, creating the potential for metal accumulation in soils and for increases in metals concentrations in streams draining the ski area. The 2001 Keystone Ski Area Water Quality Study determined that, although metals-related impacts existed on the resort's mountains, the results were not severe enough to motivate the resort to cease snow-making with Snake River water, but new snow-making projects will be further evaluated in the future [*Hydrosphere,* 2001]. Because no mine reclamation or remediation projects were initiated, the root of Keystone's problem remains unchanged in the headwaters above the resort.

Although Arapahoe Basin is isolated within an uncontaminated drainage basin, expansion of this small, alpine ski resort has likewise been hindered by the poor water quality of the Snake River. Stream water from the pristine North Fork of the Snake River was sought to enable Arapahoe Basin to make snow to extend their ski season, potentially through the summer. Arapahoe Basin saw snow-making as necessary to stay competitive with neighboring resorts, but opponents asserted that the project would alter water quality at a larger watershed scale. The high-quality waters of the North Fork dilute the metal-laden mainstem Snake River at their confluence, and it was argued that the proposed 46% depletion of winter base flows (1 December through 31 March) would increase ecosystem impacts downstream due to decreased water available for dilution [*USFS,* 1999]. To address these concerns, in conjunction with the United States Forest Service, Arapahoe Basin conducted an environmental impact statement (EIS) as a part of its master development plan. The EIS identified five alternatives, ranging from no action, to the proposed action; and following several legal challenges, a consensus was ultimately reached that allowed Arapahoe Basin to proceed with their preferred alternative [*USFS,* 1999].

Periodic Drought and Implications for Mountain Recreation

The allure of Colorado tourism, which annually injects around $9 billion into the state's economy, is the diversity of outdoor recreational activities available within close proximity to Front Range urban centers. A majority of these tourist activities rely on the availability of copious quantities of water. Colorado's ongoing drought has sounded a climatic alarm call, prompting water managers to assess their preparedness for extended periods of dryness. According to Colorado's Office of State Planning and Budgeting, this prolonged water deficiency is likely to significantly affect the economy of Colorado, primarily through the tourism and agricultural sectors. Data from the Colorado State Planning and Budgeting Office, obtained during the 1977 drought, show 2.3 million fewer lift tickets sold compared to the previous year, reflecting deflated visitation due to a lack of snow.

For the ski resorts of mountain communities, future impacts associated with climate change may extend beyond coping with an occasional, severe drought. According to the comprehensive *Climate Change 2001* report published by the Intergovernmental Panel on Climate Change, for a range of scenarios, the globally averaged surface air temperature is projected to warm 1.4 to 5.8°C by the year 2100 [*IPCC,* 2001]. Although the dynamics of climate change are complex, and predictions of regional changes are marked by uncertainty, potential ski industry specific effects are being investigated. Recent studies have concluded that changes in temperature and precipitation predicted under even the most conservative climate change scenarios could truncate season lengths, shift elevations with reliable snow cover upward, and eliminate skiing altogether in marginal areas [*Elsasser and Messerli,* 2001; *McBoyle and Wall,* 1991].

The timing of the historical explosion of ski resort development and the corresponding growth in the number of skiers is an important consideration in an assessment of the Colorado ski industry's vulnerability to changing climatic conditions. Figure 1 displays Colorado skier visitation information overlaid on the state's drought history during the last century and reveals several important trends. The periodic spikes evident within the climatic data demonstrate that drought is a common occurrence in Colorado. In fact, analysis of historical dry and wet periods in the state shows that more than 90% of the time, a minimum of 5% of Colorado is suffering drought conditions at either a 3-, 6-, 12- or 24-month time scale [*McKee et. al.* 2000]. In addition, the period of time encompassing the major growth of the ski industry (as evident in a doubling of Summit County skier visits between 1980 and 2000) was also Colorado's second-longest sustained wet period in recorded history, and the most drought-free period since 1890 [*McKee et. al.*, 2000]. Finally, there is a relationship between recent multi-year droughts and the precipitous drops in skier visits during the late 1970s and the early 1980s.

Attempts at Adaptation

In order to minimize dependence on ample snowfall, ski resort owners have begun to embrace two adaptation strategies; expanded snow-making capacity and four-season resort development. Utilizing these strategies, the idealized resort community becomes buffered from natural climate variability, creating tourist-friendly villages with recreation available during all seasons. However, as mountain communities such as Keystone continue to expand and evolve to realize their year-round economic potential, they may be approaching a carrying capacity imposed by finite, impaired water resources. Though the presence of zinc in Snake River water does not inhibit the quality of man-made snow for skiing during the winter, the quality is often too poor to sustain some primary summertime mountain activities (e.g., recreational trout fishing, golf, rafting). Thus, as water use diversifies and intensifies, water quality and quantity are likely to prove compounding limiting factors.

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Report Lays Out Initial Hazard Risk Reduction Priorities

PAGE 378

A new Bush administration report on disaster vulnerability provides an initial set of priorities for natural and technological hazard risk reduction efforts, an overview of hazards facing the U.S., and a review of current mitigation efforts.

Among the priorities identified by the 27 August report is that the U.S. should leverage scientific knowledge of natural and technological hazards to help address terrorism events and homeland security goals.

The report, "Reducing Disaster Vulnerability Through Science and Technology," notes, "Scientific and technological advances developed in the arena of natural and technological disasters also can directly benefit terrorism preparedness and response." The report adds that a common, all-hazards approach is needed to effectively address all disaster risks.

Other report priorities include: improving hazard data collection and prediction capability, developing better hazard and risk assessment models, and hastening the incorporation of hazard research into management applications.

The report was prepared by the Subcommittee on Natural Disaster Reduction, a division of the White House Office of Science and Technology Policy's National Science and Technology Council. A final report is planned for release in 2004.

Helen Wood, chair of the Subcommittee on Natural Disaster Reduction, and director of satellite data processing and distribution for the National Oceanic and Atmospheric Administration, said that major improvements in disaster mitigation, preparedness, response, and recovery are possible through strategic investment in science and technology. "We want to begin to identify major challenge areas where if we can make measurable improvements, we can reduce America's disaster losses," she said.

The interim report is "a way to amplify the message we are trying to send," she said Wood added that the potential leveraging of scientific and technological advances for natural and technological as well as terrorist events has involved an "evolution in thinking and planning" following September 11, 2001. She noted that there are many potential similarities in planning, mitigation, and response efforts.

William Hooke, director of the atmospheric policy program at the American Meteorological Society, said the report appears to be one of the first efforts by the subcommittee and the government to put natural and technological disasters in the same framework.

He said the report "is a wonderful look at the situation [of hazard management] through the rear-view mirror. Absent is any kind of statement of where things are going in the future." Hooke added that while the report is an indication that the government is thinking seriously about hazards, a key question is how much attention the issue can attract during a tight economy and facing competing priorities.

—RANDY SHOWSTACK, Staff Writer

MEETINGS

Holistic Approach Offers Potential to Quantify Mass Fluxes Across Continental Margins

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Most humans live on and utilize the continental margin, the surface of which changes continually in response to environmental perturbations such as weather, climate change, tectonism, earthquakes, volcanism, sea level, and human settlement and land use. Part of the margin is above sea level and the rest is submarine, but these land and seascape components are contiguous, and material transport from source to sink occurs as a seamless cascade. The margin responds to environmental perturbations by changing the nature and magnitude of a variety of important functions, including the distribution of soil formation and erosion; biogeochemical functioning (especially the storage and release of water, limiting nutrients and contaminants); and the form and behavior of geomorphic components from hill slopes and floodplains through the coastal zone to the continental rise. While some areas of the margin are eroding—for example, hill slopes—others accumulate sediment, such as tectonic basins and continental slope and rise. These areas record the history of surface changes.

A major goal of the Earth science community is to provide quantitative explanations and predictions of the effects of environmental perturbations on surface changes and preserved