

**Technical Report Analyzing Constantine Mining, LLC's Revised
Application for Waste Management Permit for the Palmer Phase II Exploration Project
near Haines, Alaska**

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The primary aim of this report is to provide my opinion, as a technical expert in the field of hydrogeology, on the fate and transport of discharge from a Land Application Disposal System at the Palmer Site in Glacier Creek Valley, based on existing data and analyses. In particular, I assess (1) the likelihood, timing, and nature of pollutants discharged from the proposed LAD diffusers reaching surface water; and (2) Constantine's Water Management Plan, including its assessment of underground seepage water quality and quantity and its proposed active water treatment. The scope of my opinion is limited by lack of access to the following documents, which are referenced in documents I reviewed and which contain raw data, technical details, and modelling results not reported in the documents that were available:

pHase Geochemistry, 2022, Geochemical Source Term Predictions. Palmer Project (update of 2018 report. Draft, February 2022), 21 p.

Tundra Consulting LLC, 2022, Hydrogeology Report, Palmer Project. (draft, February 2022), 380 p.

My opinion relies on the following documents:

1. Application for Waste Management Permit for the Palmer Phase II Exploration Project, Constantine, 2019, revised April 2022.
2. Appendix C Water Management Plan, Constantine Mining, 2022.
3. OUL report. Appendix D Dye Tracing Studies for a Land Application Disposal (LAD) System for Constantine Mining (Ozark Underground Laboratory, 2022).
4. Appendix E 2022 Hydrogeological Site Investigation Summary, Rev. 1 (Site Investigation Report by KCB Consultants Ltd.).
5. Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances, 2008.
6. Morin, K. A., and N. M. Hutt. "MDAG. com Internet Case Study 29 Leaching of Nitrogen Species during Underground Mining." (2008).
7. Ferguson, Keith D., and Susan Margaret Leask. "The export of nutrients from surface coal mines." (1988).

Part I. Connection between LAD diffusers and surface water.

Constantine Mining LLC plans to develop an underground exploration ramp to support drilling to a metal sulfide ore body. Planned water and wastewater disposal will be through a Land Application Disposal (LAD) system that includes a diffuser (buried perforated pipes) located in the overburden on the southeast valley flank of Glacier Creek. The diffuser is designed to accommodate a continuous flow of 700 gallons per minute (gpm) and temporary flows of 900 gpm.

Two dye tracer studies, aimed at developing an understanding of groundwater movement downgradient of the diffusers, were completed in 2019 and 2020. Stated objectives of the dye tracer studies included determining the travel time between the diffusers and Glacier Creek and nearby tributaries, locating the groundwater discharge locations that originate at the diffuser cells, and quantifying the concentration of introduced dyes in Glacier Creek (OUL, p. 11 and p. 31).

Glacier Creek receives groundwater from an alluvial fan aquifer system composed of permeable sands, silts, and gravels. Glacier Creek is relatively short (7 km) and has a relatively small watershed (39 km²), so changes to the flow field related to water disposal activities, and introduction of contaminants, are likely to result in substantial changes to the natural flow system and water quality. In addition, the groundwater gradient mirrors the steep topography, so groundwater flow will be rapid, at least in zones where aquifer sediments are permeable. Non-natural loading of water at the LAD diffusers will create an even higher hydraulic gradient toward the stream. Furthermore, the relatively small contributing watershed and high permeability fan sediments mean that groundwater is likely a large component of total stream flow. Temperature is a useful indicator of the importance of groundwater discharge for generating streamflow. Because groundwater typically maintains a temperature near the mean annual air temperature, its influx into Glacier Creek helps keep the creek from freezing during winter months (p. 43 OUL report).

Although the watershed is small, the porous materials that host groundwater are quite heterogeneous. The effects of heterogeneity are discussed further below, but highly variable flow rates within a groundwater flow field make predicting groundwater flow paths and the groundwater flux to streams uncertain. Dye tracer tests can contribute important information about groundwater flow paths, and groundwater flux when tracer recovery can be quantified.

The Ozark Underground Laboratory (OUL) report on the dye tracer studies carried out at the Palmer Project LAD, covers two different experiments (Phase 1 and Phase 2), carried out in 2 consecutive years, at proposed diffuser locations adjacent to each other (figure 1). The report describes introduction of the dyes in 3 different trenches at the Phase 1 location and 3 different trenches at the Phase 2 location (the trenches are near the proposed locations of the diffusers). The report also describes sampling methods and locations, and laboratory analysis of the dyes.

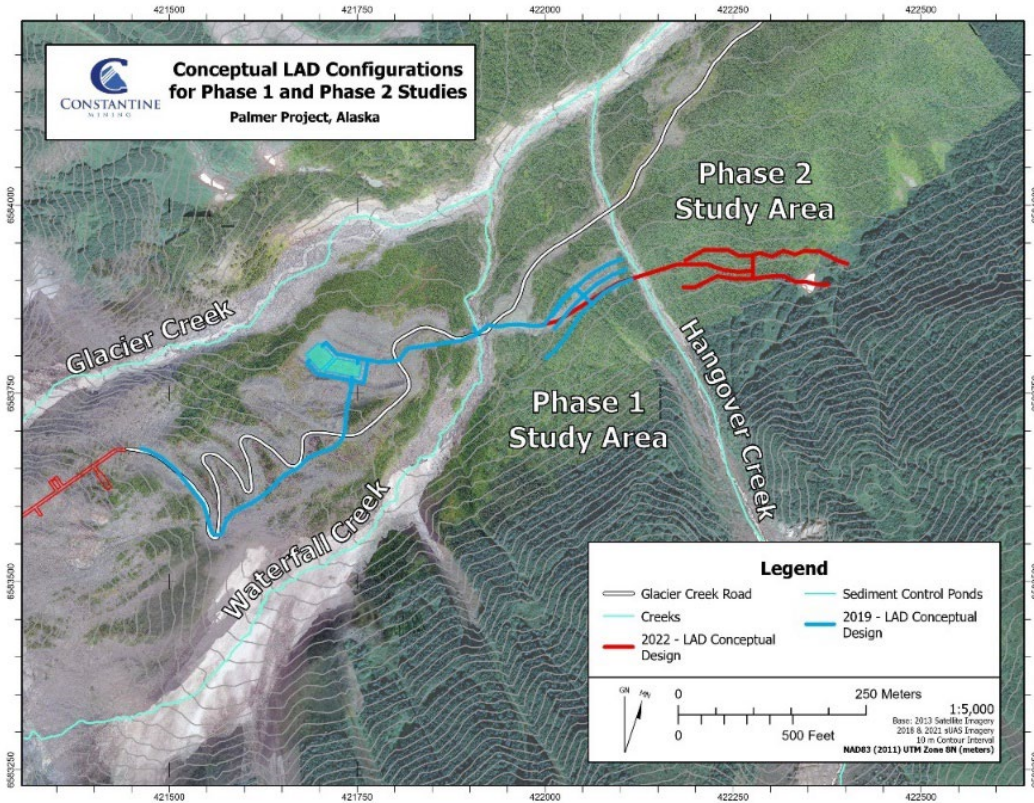


Figure 1. Map showing the Phase 1 and Phase 2 LAD locations.

Although some of the objectives were met in the Phase 1 study, the Phase 2 objectives were not met because there were no detections of dye at any of the sampling points over the time period of the study. Phase 1 results showed that tracer from trench T-3 reached Glacier Creek at one or more locations between Station 8 and Station 9 (between 935 ft and 3900 ft linear distance from T-3) after 42 days. Tracer was detected over the next 62 days, then went undetected for the next 12 or 25 days (depending on the sampler, both at Station 9). Subsequently, tracer dye was detected at a higher concentration than for the initial detections, even though collection was over a shorter time period (38 days), at one sampler. Following that, tracer was detected at both Station 9 samplers over a period of 22 days. Subsequently, no dye was detected at Station 9 (after 196 days from the time of dye introduction at T-3) until sampling ceased 648 days after introduction of the dyes. In the Phase II study, 17 sampling stations approximately 1500 to 17,500 ft linear distance from dye injection trenches were sampled over a period of 93 days, and no tracer dye was detected. (Some stations were sampled periodically up to 350 days after the dye introductions.)

The tracer detections establish a clear and relatively rapid connection between groundwater and stream water. However, the on-and-off detections of tracer indicate complex groundwater flow paths to the stream, likely caused by aquifer heterogeneity and possibly by a poorly-mixed combination of surface water and recent groundwater inflow at the sampling locations. One of the major limitations of the tracer study is that dye was not detected in water samples (only on carbon samplers that integrate over longer time periods); this means that results are not quantitative with respect to the mass of tracer recovered or dilution of tracer in the stream. In sum, the connection between groundwater and surface water could be surmised from increases in discharge with distance downstream, local groundwater gradients, and stream temperature, and that connection is confirmed by the tracer study. However, many questions about

groundwater flow paths and groundwater flux to the streams in the study area remain.

In my opinion, the final conclusion in the OUL report [“The location of the proposed 2022 Lower Diffuser is an improvement over the 2019 location as the dye tracing indicates that it does not impact Glacier Creek and its tributaries in the time interval tested.” p. 59] is too strong considering the evidence presented. Comparisons between the Phase 1 and Phase 2 studies are not robust because streamflow conditions differed by significant margins during 2019 and 2020. For example, the stream discharge in Glacier Creek was 6 times higher during Phase 2 (on September 24th, 2020; p. 58) compared to Phase 1. The measured increase in discharge with distance downstream, indicating groundwater influx, was 5 times higher during Phase 2. Of the possible reasons for non-detections of dye during Phase 2, the notion that discharge from the second location does not impact Glacier Creek and its tributaries is among the least likely. The rate of transport for groundwater from the Phase 1 and Phase 2 LAD diffuser areas, loosely determined by the dye tracer in Phase 1, is likely to be similar, and the distance between Phase 2 diffusers and Glacier Creek is only nominally greater than the Phase 1 distance, so the travel time will be similar.

The straight-line distances from diffusers to Glacier Creek are 200 m for Phase 1 and 300 m for Phase 2. The linear distance traveled by groundwater from T-3 to Station 9 is at most 3900 ft (1189 m), and groundwater entering the saturated zone at T-102/T-103 likely travels a similar distance or somewhat greater distance before entering the stream, depending on the precise direction of groundwater flow.

An independent estimate of the time of travel between the trenches and stream is obtained using Darcy’s Law. Groundwater flow is governed by Darcy’s Law, which describes the transport of water through porous media under a hydraulic (pressure) gradient,

$$q = Ki$$

where q is the specific discharge, K is the hydraulic conductivity and i is the hydraulic gradient. The linear velocity (v) of groundwater is determined by combining Darcy’s Law with the aquifer porosity, n .

$$v = \frac{q}{n}$$

Using values stated in the OUL report ($n=0.18$ on p. 11, $i = 0.25$ or 0.22 on p. 42, $K = 8.6$ m/d on p. 42), one calculates similar linear velocities for Phase 1 and Phase 2 areas; 11.9 m/d (39.2 ft/d) for Phase 1 and 10.6 m/d (34.8 ft/d) for Phase 2. Relevant distances range from the distance from the trenches to a point on the stream directly adjacent (200 m or 300 m) and the distance from the trenches to Station 9 (1189 m), or somewhat further for Phase 2 (e.g., 1500 m). The calculated travel times then range from 17 days (higher velocity, shortest distance) to 142 days (lower velocity, greatest distance). Considering the uncertainty in the determination of a representative value of K , the agreement between the range in tracer travel time (42 days to 196 days), and the range in Darcy travel time, is good. The lack of dye detection during Phase 2 is thus not likely due to a significantly different groundwater flow velocity toward the stream compared to Phase 1.

Another poorly supported conclusion is that “most of the introduced dye remained in the aquifer” (p. 54). As noted above quantitation of dye recovery or dilution is not possible with the data obtained during the study, and the sporadic nature of detections and limited sampling locations make it likely that water containing dye was not sampled (this applies to both groundwater,

sampled in 3 monitoring wells over a limited depth range, and to stream water). On p. 58, the report states, “The dataset presented in this report does not provide sufficient detail to permit reasonable estimates of groundwater contributions to Glacier Creek.” The report emphasizes the effects of heterogeneous aquifer materials in explaining lack of detection of dyes in Phase 2 and from two of the trenches in Phase 1. Appendix E does not address groundwater to surface water flow, except to say that groundwater “reports to Glacier Creek”, but does have information about sediment heterogeneity. In addition to the tracer results, evidence for heterogeneity in aquifer sediments include grain size analysis from core samples, variable K values from pump tests, and large differences in volumes retrieved during well development (including wells that went dry quickly).

In my opinion, more likely than groundwater from the Phase 2 location not having an impact on Glacier Creek and tributaries, possible reasons for a lack of dye detections include: 1) insufficient spatial and temporal sampling coverage in groundwater and in the streams, especially considering the heterogeneous nature of the aquifer materials, and 2) insufficient volume of water tagged with tracer and insufficient mass of tracer introduced. The carbon samplers are useful for accumulating dye over many days, but only sample over a small area, and rely on sampled water being thoroughly mixed, which was not the case, as evidenced by sporadic detections and variable accumulation rates. Groundwater that enters the stream at focused “hot spots” could be missed using the sampling methods employed. Ideally, to define groundwater flow paths and groundwater flux to the stream, tracer from the trenches would have been found in groundwater wells downgradient of the trenches, and in stream water. Furthermore, the water that was tagged with tracer (5,000 gal) amounts to only 10 minutes of a 500 gpm discharge, compared to a similar rate that will be applied at the diffusers but continuously, 24/7, which is a much greater volume of water, and which will result in a mound in the water table that will hasten transport away from the diffusers. It is not clear how the second location serves to “optimize groundwater flow paths in the overburden” (p. 1, revised WMP), as these flow paths are largely controlled by subsurface heterogeneity, and optimal flow paths would not flow to nearby surface water.

Part II. Available information does not allow a complete assessment of Constantine's Water Management Plan, including underground seepage water quality and quantity and the proposed active water treatment plan.

Underground seepage water (all groundwater inflows to the exploration ramp) will be pumped to the LAD diffuser, where it will enter the aquifer connected to Glacier Creek and its tributaries. The mean modelled seepage rate to the ramp is 360 gpm, which amounts to 518,400 gallons per day (1.59 acre-feet per day). This predicted rate is based on numerical modelling in Tundra Consulting (2022), which was not available for review.

Active treatment in this case includes pH adjustment, and coagulation-flocculation (with microsand) for solids settling. In addition to the conveyance and diffusers, an initial settling pond will act as the sole form of treatment when the treatment plant is inoperative (including planned maintenance), and a second pond will be used to “manage settled solids.” Depending on how often the settling ponds are used and the nature of the solids received, the ponds (if unlined) will provide additional hydraulic head or fill with sediment and lose capacity. Possible loss of infiltration capacity also applies to the diffusers, if sediment loads are higher than expected, or of a different grain size than expected.

Regarding the modelled rate of influx of groundwater to the ramp, the reports acknowledge significant uncertainty in predicted flow values, especially considering most of the flow is assumed to enter at a single active fault zone (the Kudo Fault; Figure 2). The geologic cross section shows at least three different formations that will be intercepted by the ramp. It is not clear how uncertainty in the predicted flow relates to the wide range in K values reported in Appendix E. The water management plan assumes that all seepage water will flow toward sumps and accumulate there before conveyance to the LAD diffusers, but some water will likely re-infiltrate subsurface sediments closer to its inflow location, prior to any treatment; metering the sumps will not account for this water.

Maximum predicted stormwater flows (managed under permits AKR 100000 and AKR 060000) may be underestimated because climate warming is causing more frequent extreme runoff events, and rain-on-snow events, which would lead to a high volume of sudden runoff, with high turbidity, and overflow to the emergency spillway.

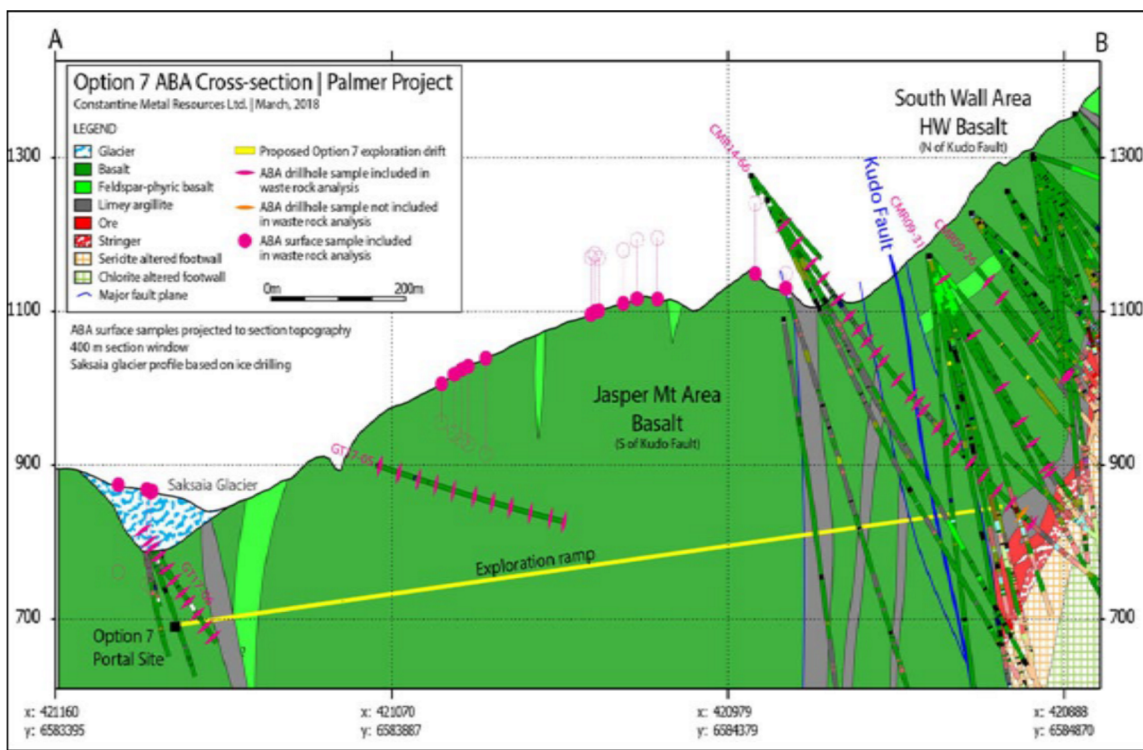


Figure 2. Geologic cross section of exploration ramp area.

With respect to water quality, storm water and seepage water will contain more sediment, due to construction activities, than these waters would contain under natural conditions, and the temperature of the water will be (mostly) increased due to holding times in ponds and exposure to atmosphere. Any additional sediment increases the likelihood of transport of all particle-associated pollutants (including pathogens, most metals, and phosphate). Furthermore, contact between water and explosives residues in the ramp will add nitrogen (N) compounds and potentially other compounds like sulfur and perchlorate. These constituents will be transported in dissolved form, unlikely to be transformed or retarded in the mostly aerobic groundwater environment. The planned treatment process is designed to minimize transport of metals in dissolved and particulate form, and will not remove nitrogen, sulfur, or perchlorate compounds.

Humidity cell concentration predictions for underground seepage water quality (Table 1 in Constantine WMP) are not reported with uncertainties, but previous studies show significant deviations between humidity cell predictions and field observations. The pHase Geochemistry report wherein the geochemical modeling is described, was not available for review. Nitrogen-containing compound concentrations are reportedly predicted using methods described in Ferguson & Leask (1998) and Morin & Hutt (2008), since they are not included in humidity cell or field barrel predictions. However, it is unlikely that these studies are applicable at the Palmer Site. Ferguson & Leask (1998) discuss N and P migration from open pit coal mines in a dry environment, in a case study based on field data. Morin & Hutt (2008) is another case study, in metal ore, that reports vastly higher percentages of N leached from blasted areas; however, Morin & Hutt (2009) emphasize the lack of documented methods for making reliable, quantitative predictions for N compound transport at mine sites. Effective monitoring for metals and N compounds would need to include speciation analysis, and decades-long sampling and analysis of groundwater and stream water downgradient of the LAD site.

In addition, in Table 1, the acute guideline (for drinking water) for Arsenic (As) should be 0.010 mg/L, Chromium should be listed as hexavalent chromium (Cr-VI), and there is a typographical error on the acute value for Pb (shows 0.10013 mg/L; the drinking water/acute limit for dissolved Pb is 0.015 mg/L).

In summary, increases in discharge with distance downstream, local groundwater gradients, and stream temperature at the Palmer site provide evidence for the connection between groundwater and surface water. That connection is confirmed by the Phase 1 tracer study results. However, many questions about groundwater flow paths and groundwater flux to the streams in the study area remain. The Phase 2 tracer study results, in which dye was not detected in streams, are more likely explained by differences in the stream and groundwater discharge rates during the second phase and/or lack of sufficient sensitivity and sampling coverage, than by a completely different flow regime in which groundwater does not report relatively rapidly to Glacier Creek. Uncertainty also remains in predictions of the volume, rate, and composition of groundwater influx to the exploration ramp, and subsequently to the diffusers. Predictions of discharge water quality are based on humidity and barrel concentration tests on 3 or 4 background water types. These tests are unlikely to reveal the range of concentrations for the various contaminants that may be released into the environment due to activities at the site.



Jean E. Moran

EMPLOYMENT

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| Professor, Department of Earth & Environmental Science, California State University East Bay | 2016-present |
| Associate Professor | 2012-2016 |
| Assistant Professor | 2008-2012 |
| Collaborating Scientist, Lawrence Livermore National Laboratory | 2008-present |
| Research Scientist, Project Leader, Lawrence Livermore National Laboratory | 1997-2008 |

EDUCATION

1994, University of Rochester, Rochester, NY, Ph.D. Geochemistry
1986, University of Washington, Seattle, WA, M.S. Geophysics
1983, University of Rochester, Rochester, NY, B.S. Geology, *cum laude* B.A. Physics, *cum laude*

RESEARCH EXPERIENCE

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| Research grants, CSU East Bay | 2008-present |
| sources of nitrate in drinking water, analysis of groundwater ages, tools for groundwater sustainability, identification of paleowater, extrinsic tracers in managed aquifer recharge settings, surface water-groundwater interaction | |
| Research Scientist, Lawrence Livermore National Laboratory | 1997-2008 |
| Project Leader Groundwater Ambient Monitoring and Assessment Program, Director noble gas mass spectrometry laboratory; water quality, surface water/groundwater interaction, groundwater age-dating | |
| Post-Doctoral Scientist, Texas A&M University | 1994-1997 |

GENERAL RESEARCH INTERESTS

groundwater recharge, dating and contamination vulnerability, mass spectrometric methods for environmental geochemistry, chemical evolution of fluids in the earth's crust, applications of isotopes in hydrogeology and environmental geology, artificial recharge, public health and drinking water quality

TEACHING EXPERIENCE

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|---|--------------|
| California State University East Bay | 2008-present |
| Courses taught: Groundwater Chemistry (graduate), Hydrogeology, Environmental Hydrology, Oceanography, Natural Disasters, Physical Geology, Oil Water and Future Earth, Contaminant Transport (graduate), Isotope Geochemistry (graduate), Undergraduate Capstone, Graduate Seminar | |

PROFESSIONAL MEMBERSHIPS

American Geophysical Union, Geological Society of America, National Association of Geoscience Teachers
Groundwater Resources Association of California **Board of Directors 2006-2011**

HONORS, AWARDS, RECOGNITION

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| Outstanding Researcher, Tenured, CSUEB | 2017 |
| Best Paper of 2014, International Consortium on Geo-disaster Reduction | 2014 |
| Hitchon Award - International Association of Geochemistry | 2007 |
| Groundwater Resources Association President's Award | 2007, 2008, 2009 |
| Outstanding Mentor to Students, LLNL | 2006 |

REVIEWER

Nature Communications, Hydrogeology Journal, Water Resources Research, Environmental Science and Technology, Water Resources Research, Hydrological Processes, Geochimica et Cosmochimica Acta, Journal of Hydrology, Ground Water, Applied Geochemistry, Water (MDPI), Journal of Environmental Quality, Science of the Total Environment, Nitrogen Assessment Project (UC Davis), National Science Foundation

Selected Publications (*peer-reviewed; ± student author)

*Grande, E.± and Moran, J.E. Patterns in Radon in California Groundwater. *ES&T Water* **2021**, <https://doi.org/10.1021/acsestwater.1c00226>

*Grande, E.±, Visser, A., Moran, J.E. Catchment storage and residence time in a periodically irrigated watershed. *Hydrological Processes* **2020**, 34 (14), 3028-3044; <https://doi.org/10.1002/hyp.13798>.

*de Jong, M.±, Visser, A., Moran, J.E. Identifying Paleowater in California Drinking Water Wells. July **2019** *Quaternary International* DOI: 10.1016/j.quaint.2019.04.008

*Grande, E.±, Visser, A., Beitz, P., Moran, J.E. Examination of Nutrient Sources and Transport in a Catchment with an Audubon Certified Golf Course. *Water* **2019**, 11(9), 1923; <https://doi.org/10.3390/w11091923>

*Veale, N±; Visser, A.; Esser, B.; Singleton, M.J.; Moran, J.E. Nitrogen Cycle Dynamics Revealed Through $\delta^{18}\text{O}-\text{NO}_3^-$ Analysis in California Groundwater. *Geosciences* **2019**, 9, 95.

*Visser, Ate; Jean E. Moran, Michael J. Singleton, Bradley K. Esser "Importance of river water recharge to the San Joaquin Valley groundwater system" *Hydrological Processes*, <https://doi.org/10.1002/hyp.11468>, **2018**

*Avery, Elizabeth±; Bibby, R.; Visser, A.; Esser, B.; Moran, J.E. Quantification of Groundwater Discharge in a Subalpine Stream Using Radon-222. *Water* **2018**, 10, 100.

*Peters, Elizabeth±; Visser, A.; Esser, B.K.; Moran, J.E. Tracers Reveal Recharge Elevations, Groundwater Flow Paths and Travel Times on Mount Shasta, California. *Water* **2018**, 10, 97.

*Lucas, Ryan G.±, Francisco Suárez, Martha H. Conklin, Scott W. Tyler, and Jean E. Moran 'Polymictic Pool Behavior in a Montane Meadow, Sierra Nevada, CA', *Hydrological Processes*, *Hydrological Processes* 30(18):DOI10.1002/hyp.10834 March, **2016**.

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*Harms, Patrick±; Visser, Ate; Moran, Jean; Esser, Bradley 'Distribution of Tritium in Precipitation and Surface Water in California' *Journal of Hydrology*, DOI: 10.1016/j.jhydrol.2015.12.046, March, **2016**

*Visser, Ate; Moran, Jean; Hillegonds, Darren; Singleton, Michael; Kulongoski, Justin; Belitz, Kenneth; Esser, Bradley 'Geostatistical Analysis of Tritium, Groundwater Age, and Other Noble Gas Derived Parameters in California', *Water Research* 91, DOI: 10.1016/j.watres.2016.01.004, Jan, **2016**.

*Segal, D.C.±, Moran, J.E., Visser, A., Singleton, M.J., and Esser, B.K. **2014** "Seasonal Variation of High Elevation Groundwater Recharge as Indicator of Climate Response", *Journal of Hydrology*, v. 519:3129-3141.

*Bensen, A.±, Zane, M.±, Becker, T.±, Visser, A., Urióstegui, S., DeRubeis, E.±, Moran, J. E., Esser, B., K., Clark, J. **2014** "Quantifying Reaeration Rates in Alpine Streams using Deliberate Gas Tracer Experiments", *Water*, 6(4):1013-1027.

*Visser A., Singleton M., Hillegonds D., Velsko C., Moran J. E., and Esser B. K. **2013** A membrane inlet mass spectrometry system for noble gases at natural abundances in gas and water samples, pp. 40. *Rapid Communications in Mass Spectrometry*, Volume 27, Issue 21, 2472–2482 doi: 10.1002/rcm.6704

*O'Leary, D.R., Izbicki, J.A., Moran, J.E., Meeth, T., Nakagawa, B., Metzger, L., Bonds, C., Singleton, M.J. **2011** Movement of Water Infiltrated from a Recharge Basin to Wells. *Ground Water* doi: 10.1111/j.1745-6584.2011.00838.x.

*Singleton, M.J. and Moran, J.E. **2010** Dissolved noble gas and isotopic tracers reveal vulnerability of groundwater in a small, high elevation catchment to predicted climate changes. *Water Resources Research* doi: 10.1029/2009WR008718.