Siskiyou County Flood Control and Water Conservation District

Improving Groundwater Management in the Shasta Valley through Integrated Hydrologic Modeling and Decision Support

Applicant Name: Siskiyou County Flood Control and Water Conservation District

Applicant Address: 1312 Fairlane Road, Yreka, CA 96097

Project Manager Name: Matt Parker, Groundwater Sustainability Agency Manager

Project Manager Address: 1312 Fairlane Road, Yreka, CA 96097

Project Manager Email: mparker@co.siskiyou.ca.us

Project Manager Phone: 530-842-8005

Table of Contents

3. Executive Summary

3a. Date, Applicant, and Location Information

Date: July 8, 2026

Applicant: Siskiyou County Flood Control and Water Conservation District

Location: Yreka, Siskiyou County, California

3b. One-Paragraph Project Summary

The Siskiyou County Flood Control and Water Conservation District (District), acts as the Groundwater Sustainability Agency (GSA) for the Shasta Valley Groundwater Basin. The District is tasked with implementing Groundwater Sustainability Plans (GSP) under the state of California's Sustainable Groundwater Management Act (SGMA). The District, with technical support from Larry Walker Associates (LWA) and Lawrence Livermore National Laboratory (LLNL), respectfully submits the below project proposal that will develop and apply a suite of integrated hydrologic science tools to advance groundwater sustainability planning in the Shasta Valley basin. The project will develop a high-resolution Big Springs Submodel nested within the existing Shasta Valley Integrated Hydrologic Model, conduct a multi-tracer isotopic investigation of springs near and within the Lake Shastina and Big Springs Complex areas in partnership with LLNL. Additionally, the project will develop a seasonal climate forecasting and basin response tool adapted from a framework successfully demonstrated in the adjacent Scott River watershed, and create AI agents to develop interactive, publicly accessible stakeholder engagement visualization tools. These products will improve the quantitative foundation for sustainability plan implementation, reduce critical hydrogeologic uncertainties, and enhance the ability of water managers and the District to make proactive, informed decisions under conditions of seasonal variability and long-term climate uncertainty, directly advancing the WaterSMART Applied Science Grants program's goals of developing hydrologic information and decision support tools that improve water management in the Western United States.

3c. Project Timeline and Estimated Completion Date

Several components of the proposed work are part of an ongoing, non-federal implementation grant, under which early-stage project activities are anticipated to begin in summer 2026. Work is anticipated to continue in fall 2027 following execution of the financial assistance agreement, with an estimated completion date of September 30, 2029.

3d. Federal Facility Statement

The proposed project is not located on a federal facility.

4. Technical Project Description

This section describes the work to be performed, the methods and tools to be used, and the goals of the Project. Project benefits are addressed under Criterion B; the schedule and work plan are addressed under Criterion C.

4a. Applicant Category

The applicant, the Siskiyou County Flood Control and Water Conservation District, is a Category A entity under this funding opportunity. The District is a local governmental entity organized under the California Water Code, with authority over water conservation and flood control within Siskiyou County. It serves as the exclusive Groundwater Sustainability Agency for the Shasta Valley Basin under California's Sustainable Groundwater Management Act (the state's groundwater law), with authority established by Siskiyou County Resolution FLD17-01 (April 4, 2017). The District is in the Western United States, within a Reclamation State.

The District is the Category A applicant; no Category B partnership applies.

4b. Detailed Project Description

Big Springs Submodel Development

Big Springs Creek (BSC) is recognized as one of the most ecologically significant tributaries in the Shasta River watershed and, by extension, the Klamath River basin. BSC functions as a primary source of cold, nutrient-rich water to the Shasta River during spring and summer months, a period when cold-water availability is the most limiting factor for threatened coho salmon and other cold-water-dependent species that over-summer in the watershed.

The Big Springs area is underlain by a high-yielding fractured basalt formation that is presumed to be hydraulically connected to BSC and other nearby spring source formations. This interconnection has significant regulatory implications. The State Water Resources Control Board (SWRCB) and the Scott Shasta Watermaster District (a court-appointed official responsible for administering water rights under the Shasta River adjudication) regulate water use. SWRCB emergency drought regulations have curtailed non-overlying (appropriative) groundwater rights in the Big Springs area specifically based on this presumed interconnection. However, because of the complex heterogeneity and aquifer structure (fractured basalt aquifer interfacing with an alluvial aquifer), the nature and degree of this interconnection are not well characterized, and more data and a refined model are critical to design effective management solutions.

The Shasta Valley Integrated Hydrologic Model (SVIHM) developed by LWA and implemented in USGS's MODFLOW finite-difference framework is the primary quantitative tool supporting the Shasta Valley sustainability plan. The SVIHM simulates the entire 2,000 km² watershed using a four-layer model with 270-meter by 270-meter grid cells and monthly stress periods spanning water years 1991 through 2025. While this basin-wide model is well-suited for evaluating watershed-scale water budgets and regional groundwater flow patterns, its spatial resolution limits its utility for localized questions about groundwater-surface water interaction in the heterogeneous Big Springs region.

The primary goal of this task is to develop a high-resolution submodel of the Big Springs area, nested within the existing SVIHM framework, that can more accurately characterize groundwater-surface water interaction in this hydrogeologically complex and management-critical region. Specific objectives include developing a refined subgrid model incorporating updated hydrologic data and improved representation of local aquifer parameters to improve water budget accounting and characterize the relationship between groundwater pumping, aquifer storage, and spring discharge. The refined model will also support scenario-based analyses to evaluate the potential effects of water management actions on spring flows and groundwater levels in the Big Springs area, in support of adaptive implementation of the basin's sustainability plan.

Model calibration will be performed using machine learning (ML)-based approaches. Specifically, a neural network regressor in which global sensitivity analysis identifies the most influential parameters, then predicts optimal parameter values to reproduce observed conditions. This approach has demonstrated strong performance in calibration MODFLOW models in complex hydrogeological settings while substantially reducing the computational burden of traditional calibration methods (Montoya, 2020).

Incorporation of AI-assisted calibration directly advances the Federal Administration's priorities for artificial intelligence in Federal programs, as articulated in E.O. 14154, OMB M-25-21 (Accelerating the Use of AI through Innovation, Governance, and Public Trust), and S.O. 3444 (Leading Interior's Path to Artificial Intelligence Transformation).

This task is expected to produce:

- A calibrated, high-resolution Big Springs Submodel nested within the existing SVIHM framework, with documentation of model development, data inputs, and calibration results;
- An improved water budget for the Big Springs Region characterizing the relationship between groundwater pumping, aquifer recharge, and spring discharge; and
- Scenario modeling results and associated technical documentation suitable for use by the District and water management partners in support of sustainability plan implementation and adaptive management.

Lawrance Livermore National Laboratory Isotopes

Lake Shastina (Dwinnell Reservoir) is a central surface water feature of the Shasta Valley and a key component of the basin's water supply infrastructure. A number of small springs discharge in proximity to the Lake Shastina-Big Springs corridor, yet the source of water supplying these springs is not currently well understood. Depending on location, springs may be fed by deep, high-elevation snowmelt recharging through the volcanic aquifer system associated with Mt. Shasta, by shallow seepage from Lake Shastina itself, or by deep volcanic aquifer discharge unrelated to the lake. If lake seepage is a significant source, changes to lake operations could affect spring flows and the groundwater-dependent systems relying on them. If the springs are instead fed by deep volcanic aquifer recharge, their long-term behavior would be more closely tied to shifts in snowpack and climate. Resolving this question will improve the conceptual model underlying the basin's MODFLOW simulation, support more accurate water budget accounting, and help inform management decisions regarding Lake Shastina operations and the connectivity of groundwater sources feeding Big Springs.

The primary goal of this task is to identify and characterize the sources of water discharging in small springs across the Lake Shastina-Big Springs corridor through a multi-tracer isotopic investigation, and to use those findings to improve the hydrogeological conceptual model.

This task will be conducted in partnership with LLNL, whose Nuclear and Chemical Sciences Division maintains specialized laboratory infrastructure for the full suite of environmental tracers proposed herein. LLNL scientists have extensive experience applying these methods in northern California volcanic systems, including prior work in and nearby Shasta Valley.

The approach leverages the complementary diagnostic power of multiple independent isotopic and geochemical tracers to differentiate among candidate water sources across the corridor. Because both high-elevation Mt. Shasta snowmelt and Lake Shastina water ultimately originate from similar high-elevation precipitation, the stable isotope signatures of the two sources may be similar under some conditions. Reliance on any single tracer would therefore risk inconclusive results. The multi-tracer design described below is specifically constructed to maximize diagnostic confidence by exploiting physical processes that affect each candidate source differently such as evaporation, radioactive decay, atmospheric equilibration, and terrigenic gas accumulation.

The tracer suite utilizes a combination of tools to investigate the age, transit time, and ideally, source of different waters in the eastern part of the basin, including Big Springs areas. Stable hydrogen and oxygen isotopes ($\delta^{2}H$, $\delta^{18}O$) are used to estimate recharge elevations and detect the evaporative enrichment characteristic of lake seepage. Tritium differentiates old deep-aquifer water from young shallow-seepage water based on radioactive decay since peak nuclear testing. Noble gases independently constrain recharge elevation and, through terrigenic helium with mantle-type isotope ratios, identify direct volcanic aquifer recharge. Lastly, radon is used to indicate subsurface residence time, with elevated concentrations pointing to deep aquifer recharge rather than short, shallow lake-seepage pathways. Results across tracers will be synthesized to attribute each spring's source with high diagnostic confidence, and findings will be used to update SVIHM parameters accordingly.

This task is expected to produce:

- A documented isotopic and geochemical dataset characterizing springs across the Lake Shastina-Big Springs corridor and lake end-member samples;
- A technical memorandum presenting analytical methods, source attribution findings, and comparisons with the existing groundwater model; and
- Documented revisions to the Shasta Valley groundwater model reflecting improved understanding of groundwater-surface water interaction along the Lake Shastina-Big Springs corridor and planned additional simulations to refine calibration and understanding of the flow system (e.g., ModPath).

Climate Forecasting Tool

A similar challenge has been addressed in the adjacent Scott River watershed through the development of a seasonal watershed behavior classification and forecasting framework (Kouba and Harter, 2024), which demonstrated that relationships between climatic inputs and surface and groundwater responses could be quantified to support more anticipatory water management. The Shasta Valley's distinct, volcanic and spring dominated hydrogeological setting necessitates a basin-specific application and calibration of this framework.

The goal of this task is to develop and apply a seasonal climate forecasting and basin response tool for the Shasta Valley watershed using that framework. The tool will characterize how the Shasta Valley basin responds to varying climatic conditions across seasons and water year types and will provide water managers and the District with an improved basis for anticipating surface water and groundwater resource availability under current and forecast conditions.

This task will classify seasonal watershed behavior into distinct hydrologic response categories using a threshold-based approach that identifies breakpoints in basin response to climatic drivers including precipitation, snowpack, and temperature. The classification framework will be developed using existing monitoring data from weather stations, CDEC snow stations, stream gages, and groundwater level records. Statistical relationships between climatic inputs and basin hydrologic responses including streamflow and groundwater levels will be quantified for each behavioral category, providing a basis for anticipating basin conditions given observed or forecast climate inputs. The framework will be calibrated to the Shasta Valley's distinctive hydrogeological characteristics, including the dominant role of volcanic aquifer storage, large spring complex contributions to late-season baseflow, and the orographic precipitation variability driven by Mt. Shasta and the Klamath Mountnains.

Once developed, the tool will allow water managers to identify which seasonal behavioral regime the basin is currently in or is likely to enter, and to anticipate the corresponding implications for surface water and groundwater resource availability. Predictions will be accompanied by uncertainty characterization, providing water managers with confidence levels to inform decision-making under variable hydrologic conditions. This anticipatory information supports more proactive management responses, including earlier adjustments to groundwater pumping, storage operations, and conjunctive use strategies.

This task is expected to produce a documented seasonal climate forecasting and basin response tool calibrated to the Shasta Valley watershed, along with technical documentation describing the methodology, data inputs, calibration approach, and guidance for use by water managers and District staff.

AI Stakeholder Engagement

Effective public engagement in water resources management requires translating complex technical information such as groundwater model outputs, subsurface geology, hydrological data, and engineering analyses into forms accessible to a broad audience. The Shasta Valley sustainability plan process engages diverse stakeholders including agricultural water users, municipal representatives, tribal partners, regulatory agencies, and elected officials, each with different technical backgrounds and informational needs.

Traditionally, producing high quality public facing visualization and engagement tools has required months of development, limiting tailored communication for each project or audience. Recent advances in AI agent technology offer a meaningful opportunity to change this. AI agents can be directed by technical staff to ingest complex datasets and assemble them into interactive, browser-based visualization tools, compressing development timelines and making project-specific engagement materials practical as a routine part of water resources work. The goal of this task is to deploy AI agents as an internal resource for technical staff to develop interactive, browser-based visualization tools that communicate Shasta Valley groundwater program findings to a broad, non-specialist audience. These tools will present complex hydrological, geological, and modeling information in navigable, intuitive formats for a broad audience with varying technical backgrounds. LWA has developed and applied this AI-assisted visualization approach on other water resources projects, demonstrating the feasibility and effectiveness of the method in translating complex technical datasets into compelling public engagement tools.

Figure 1 provides an example of a tool developed using this approach for a prior project.

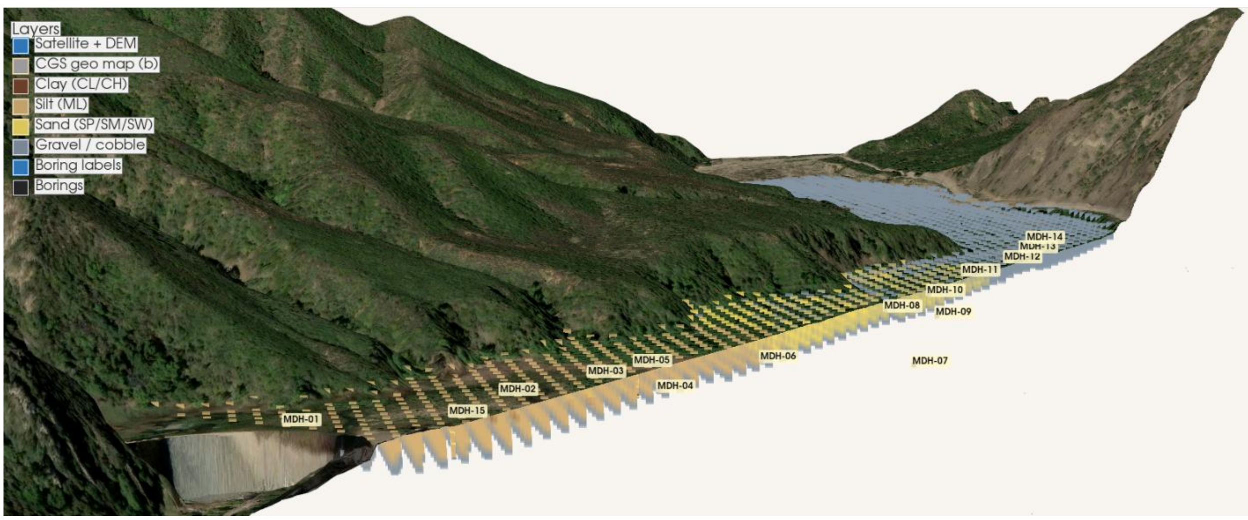

Figure 1 Example AI-assisted visualization tool developed as a proof-of-concept for Matilija Canyon, CA.

This task is expected to produce one or more publicly accessible, browser-based interactive visualization tools presenting Shasta Valley groundwater program datasets and model results in formats accessible to a broad, non-specialist audience. In addition, the task will yield a suite of AI agents available to the technical team for ongoing development of public engagement visualization tools, along with documentation supporting their continued use and maintenance by the District and project partners.

4c. Goals and Objectives

The overarching goal of this project is to improve the quantitative and scientific foundation for groundwater sustainability planning and water management decision-making in the Shasta Valley basin. The four project tasks are complementary efforts that together address the most critical hydrogeologic uncertainties limiting effective sustainability plan implementation and adaptive management in the basin.

5. Project Location

The proposed project is located in the Shasta Valley Groundwater Basin, situated in Siskiyou County in northcentral California. The Shasta River, a tributary of the Klamath River, drains the valley from south to north and serves as the primary surface water feature of the basin. The project area spans the full extent of the Shasta Valley Groundwater Basin, with focused field activities concentrated in the Big Springs complex in the central-eastern portion of the valley and the Lake Shastina area in the central valley. Together this forms a corridor where isotopic sampling will be conducted in addition to the Big Springs Submodel's focus on the Big Springs complex.

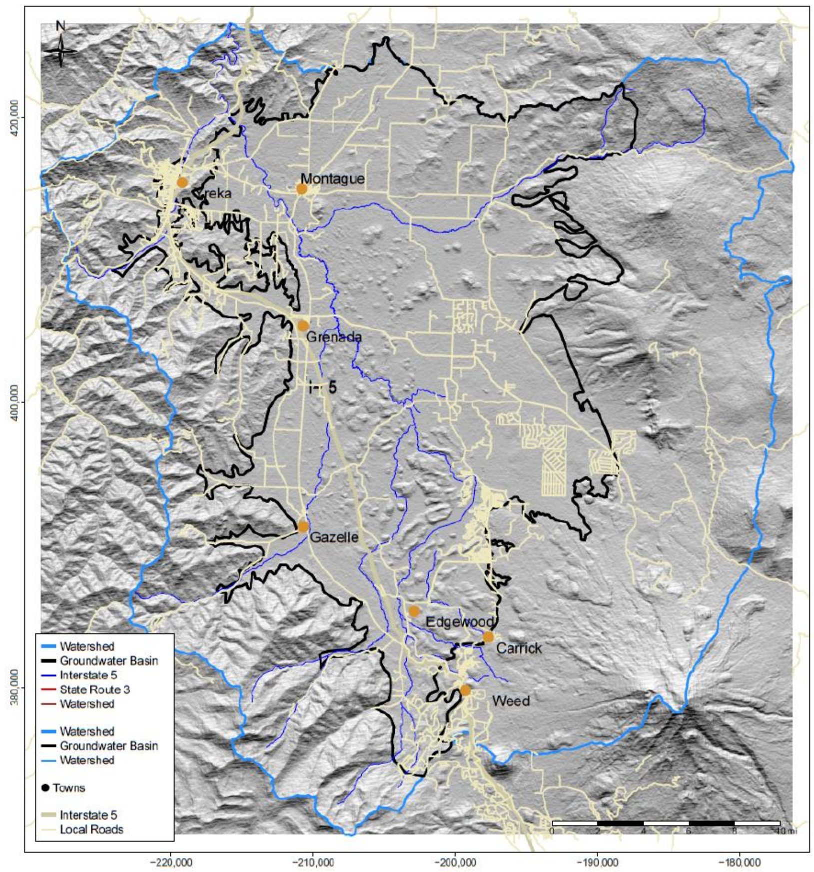

Figure 2 Map of project area.

6. Data Management Practices

All data and tools developed under this project will be managed in open, industry-standard formats to ensure long-term accessibility, reproducibility, and compatibility across platforms. Spatially explicit data including basin boundary files, monitoring network locations, recharge zone delineations, and model grid outputs will be developed and delivered in GIS-compatible formats including shapefile (.shp), GeoTIFF (.tif), and KMZ/KML, compatible with both ESRI ArcGIS and open-source platforms such as QGIS. Hydrologic model inputs, outputs, and calibration files associated with the Shasta Valley Integrated Hydrologic Model will be maintained in standard MODFLOW format with supporting data stored in CSV and NetCDF formats suitable for spatiotemporal analysis and transfer to other regional modeling efforts. Time-series monitoring data (groundwater levels, streamflow, isotope results) will be archived in CSV format with accompanying metadata. Code developed for the web-based decision-support tool and any AI-assisted visualization components will be maintained in a version-controlled repository (e.g., GitHub) and delivered in open, documented formats. All project deliverables will be accompanied by metadata following Federal Geographic Data Committee (FGDC) standards. Data will be made available to Reclamation and project partners upon request throughout the project period, with final datasets submitted as part of the project closeout package.

7. Merit Review Criteria

Criterion A: Water Management Challenge(s) (20 points)

A.1 The water management problem in the project area. The Shasta Valley Basin is a ~217,980-acre groundwater basin in Siskiyou County, California, supporting agricultural, municipal, domestic, tribal, and environmental water uses across a predominantly disadvantaged community. The basin's hydrology is dominated by snowmelt-driven recharge through highly permeable volcanic aquifers, with surface water and groundwater supplies strongly linked to winter snowpack accumulation and spring snowmelt timing. Water managers and the District must make consequential decisions about water allocation, groundwater pumping, and conjunctive use operations under conditions of high seasonal and interannual variability. Critical uncertainties remain in understanding the basin's hydrogeologic system, including the sources and behavior of major spring complexes, the relationship between high-elevation recharge and groundwater-dependent ecosystems and the basin's long-term response to shifting climate conditions. These unresolved uncertainties limit the District’s ability to implement the sustainability plan with confidence and make proactive management decisions.

A.2 Severity of the problem. The Shasta Valley basin faces intense, competing demands for water across agricultural, municipal, domestic, tribal, and environmental uses, all of which are dependent on a highly variable, snowmelt-driven water system with limited storage and an incompletely characterized hydrogeology. Agricultural pumping averages approximately 43,000 acre-feet per year, while groundwater leakage to streams averages 219,000 acre-feet per year. These fluxes are highly sensitive to drought-driven shifts in recharge. The severity of this vulnerability was starkly demonstrated in 2021, when an unprecedented drought resulted in widespread curtailments of surface water and groundwater users across the Shasta River Watershed. Every community in the basin qualifies as a Disadvantaged Community or Severely Disadvantaged Community under California’s DWR classification. These communities depend on groundwater as their primary drinking water source, and their local economies are centered on agriculture, both of which are directly vulnerable to water stress. The basin also supports federally threatened coho salmon and a suite of groundwater-dependent ecosystems, whose viability is directly tied to groundwater discharge to streams particularly in late-season when baseflow is sustained by volcanic aquifer storage. Competing demands among irrigators, municipal users, tribal interests, and environmental flows are well documented and unresolved. The limited understanding of key quantitative relationships between snowpack, recharge, groundwater storage, and spring discharge significantly constrains the District's ability to manage them effectively.

A.3 Consequences if the problem remains unaddressed. Without improved hydrogeologic characterization and better tools for anticipating water availability, water managers cannot make informed, proactive decisions to equitably serve all basin water users. Continued uncertainty about spring sources and behavior leaves managers unable to protect the late-season baseflow that threatened salmon species depend on, risking further regulatory constraints on agriculture and water supply operations. Disadvantaged communities relying on groundwater as their sole drinking water source remain vulnerable to supply disruptions that cannot be anticipated without a clearer understanding of aquifer dynamics. More broadly, decisions made without anticipatory tools will remain reactive, increasing the likelihood that drought conditions result in curtailments and supply failures that better advance information could have avoided.

Criterion B: Project Benefit (25 Points)

B.1 How does the project increase water yield, ensure water supply reliability, improve water deliveries, improve drought management, increase flexibility in water operations, enhance water supply forecast skill, and improve watershed health?

While this project does not directly increase water yield, improved characterization of aquifer recharge sources and storage will support management actions that optimize use of available supplies across seasons and water year types. Resolving key hydrogeologic uncertainties through the Big Springs Submodel and isotope study will give water managers and the District a stronger quantitative basis for planning reliable water supplies and conjunctive use decisions, including how Lake Shastina operations influence spring discharge along the Lake Shastina-Big Springs corridor. The seasonal climate forecasting and basin response tool will allow managers to identify drought conditions earlier and anticipate basin-wide hydrologic responses weeks to months in advance. This directly enhances forecast skill and enables more proactive adjustments to groundwater pumping, storage, and conjunctive use operations. Finally, resolving uncertainties around spring sources and late-season baseflow will directly support protection of cold-water habitat for federally threatened coho salmon and other groundwater-dependent species in the Shasta River system.

B.2. How was the project identified, who will use the tools and who benefits, and how and when will results be applied?

The project emerged directly from data gaps and management needs identified by the District through implementation of the Shasta Valley sustainability plan and subsequent data gap analyses. Each component responds to specific near-term priorities: the Big Springs Submodel addresses a well-documented model limitation flagged in the sustainability plan, the isotope study builds on prior LLNL work in the basin to resolve unresolved spring source questions with direct management implications, and the seasonal forecasting tool extends a methodology successfully demonstrated in the adjacent Scott River watershed. The primary users will be the District and its technical staff, along with water managers, irrigation districts, and the Watermaster, who will draw on project outputs to inform operational decisions. Agricultural operators, municipal water users, tribal interests, disadvantaged communities, and environmental stakeholders involved in coho salmon recovery will all benefit from more informed and equitable management of shared water resources. All project deliverables are designed for immediate application upon completion, and the AI agents developed under the stakeholder engagement task will remain available to the technical team as an ongoing resource beyond the project period.

B.3. Applicability elsewhere and transferability. Several project components have strong transferability. The seasonal forecasting framework is explicitly adapted from the methodology of Kouba and Harter (2024), which was developed and demonstrated in the adjacent Scott River watershed, and is designed to be applicable to other snowmelt-dominated basins with similar hydroclimate characteristics across the western United States. Application to a new basin would require basin-specific calibration using local monitoring data. The isotope-based approach for characterizing groundwater age and recharge sources is a well-established methodology that LLNL has applied across multiple western basins and will contribute to the broader body of knowledge on similar systems. The AI-assisted stakeholder engagement tools are designed using open, documented frameworks and could be adapted by other water agencies seeking to improve public communication of complex hydrologic information with minimal additional development.

B.4 Complements, not duplicates, similar efforts in the area. This project is directly coordinated with and complementary to several ongoing efforts in the Shasta Valley. One such project is the Montague Water Conservation District's conjunctive use and flow enhancement work in the Big Springs region. The hydrogeologic characterization and improved water budget accounting from the Big Springs Submodel will directly support MWCD's ability to quantify and verify the benefits of their infrastructure investments. The State Water Resources Control Board’s watershed-scale LSPC-MODFLOW model, developed to inform the Shasta River instream flow requirements, is complementary rather than duplicative: it supplies basin-wide surface water-groundwater boundary conditions, while the Big Springs Submodel’s fine-scale hydrogeologic detail will refine the Board’s representation of spring-fed baseflow in this critical reach. The LLNL isotope study extends prior collaborative work between LWA and LLNL in the basin, building on an established scientific foundation rather than duplicating it. The seasonal forecasting tool adapts the methodology of Kouba and Harter (2024), which was developed and validated in the adjacent Scott River watershed, applying a proven approach to a basin where it has been identified as a specific management need. An irrigation efficiency study collecting soil moisture and evapotranspiration data across the basin will improve the accuracy of agricultural water use inputs to the SVIHM, directly strengthening model calibration. An ongoing well inventory and risk assessment effort is improving the spatial accuracy of groundwater level data available for modeling. A new recharge pilot project in the Grenada area aimed at preventing domestic well outages during drought will benefit from the improved understanding of aquifer recharge dynamics this project provides. All project deliverables are designed to integrate with and strengthen the existing SVIHM framework, ensuring this project advances rather than duplicates the basin's cumulative modeling and monitoring investments.

B.5 How benefits will be assessed and verified. Benefits will be assessed against well-established baselines documented in the Shasta Valley sustainability plan, including historical groundwater level records from the basin monitoring network, streamflow records at existing USGS gages, and the current SVIHM water budget. Big Springs Submodel performance will be quantified using standard calibration metrics including root mean square error and coefficient of determination comparing simulated groundwater levels and spring discharge against observed values, building on the calibration framework of the existing SVIHM. The seasonal forecasting tool's skill will be evaluated against historical hydrologic records using the same validation approach demonstrated by Kouba and Harter (2024) in the Scott River watershed. The isotope study results will be evaluated against existing geochemical data and used to update key assumptions underlying the SVIHM. The District's existing monitoring networks provide the quantitative baseline for ongoing evaluation of all project deliverables.

B.6 Cost per acre-foot of water created. This project develops hydrogeologic information, modeling tools, and decision-support capabilities rather than directly creating, conserving, or delivering water. A cost per acre-foot estimate is therefore not applicable. The benefits of this project are realized indirectly through improved water management decisions that will support more efficient and sustainable use of existing water supplies over time.

Criterion C: Project Implementation (20 Points)

C.1 Approach and methodology. The project employs four integrated methodological approaches, each representing the best available technique for its specific objective.

The Big Springs Submodel is built as a high-resolution unstructured grid model using MODFLOW 6 and FloPy, nested within the existing SVIHM. Developing a local grid refinement rather than a standalone model preserves the well-calibrated regional boundary conditions of the SVIHM while directing increased spatial resolution toward the management-critical Big Springs area. Model calibration will leverage machine learning-based approaches, which have demonstrated strong performance for calibrating MODFLOW models in geologically complex settings and substantially reduce the computational burden of the inverse problem compared to traditional methods (Baalousha, 2025; Montoya, 2020).

The isotope study employs a multi-tracer approach combining stable isotopes (δ^2H, $\delta^{18}O$), tritium/helium-3, radiocarbon, and noble gases to characterize spring sources across the Lake Shastina-Big Springs corridor. Because the two candidate source waters share similar precipitation origins, a single-tracer approach would risk inconclusive results. The multi-tracer design instead exploits distinct physical processes that affect each source differently, maximizing diagnostic confidence. LLNL's specialized laboratory infrastructure and extensive experience with these methods in northern California volcanic systems makes them uniquely qualified to execute this work.

The seasonal forecasting tool is built on the watershed behavior classification framework of Kouba and Harter (2024), which was successfully demonstrated in the adjacent Scott River watershed using 78 years of streamflow records and validated against historical water year types. This approach is preferable to physics-based hydrologic modeling for near-term operational forecasting because it produces actionable, interpretable outputs without requiring complex model runs. The statistical relationships between snowpack, precipitation, and basin response can be updated annually as new monitoring data accumulate.

The AI-assisted stakeholder engagement tools draw on large language model capabilities to translate complex model outputs and hydrogeologic data into accessible visualizations and communications. This approach is well-suited to the challenge of public engagement in technically complex water management contexts, where traditional reporting formats often fail to reach diverse stakeholder audiences.

C.2 Work plan, schedule, milestones, and costs per task. The project is organized into four tasks over a two year period of performance.

Task	Description	Months
1	Big Springs Submodel Development (develop high-resolution MODFLOW 6 submodel nested within the SVIHM, sensitivity analysis and ML-assisted calibration, water budget and scenario analyses for the Big Springs area)	1-24
2	LLNL Isotope Study (multi-tracer isotopic investigation of springs near Lake Shastina; stable isotopes, tritium, noble gases, and radon; source attribution and groundwater model refinement)	1-24
3	Seasonal Climate Forecasting and Basin Response Tool (classify Shasta Valley hydrologic response categories; quantify relationships between climate inputs and surface/groundwater responses; basin-specific calibration)	1-24
4	AI-Assisted Stakeholder Engagement Visualization Tools (browser-based interactive tools for public engagement; AI agents ingesting model outputs, geology, and hydrologic data; tools for diverse stakeholder audiences)	1-24
5	Project Management	1-24

Milestone	Approx. Timing
Project kickoff; data compilation and SVIHM review complete	Month 3
Big Springs Submodel initial development and calibration complete	Month 12
LLNL isotope field sampling complete; initial data returned from laboratory	Month 12
Seasonal climate forecasting tool development and calibration complete	Month 14
LLNL source attribution findings and model refinements complete	Month 20

Milestone	Approx. Timing
Big Springs Submodel scenario analyses and technical documentation complete; AI stakeholder visualization tools deployed	Month 22

Costs per task. Estimated costs by task are provided in the separate Budget Narrative.

C.3 Anticipated products. These are listed in the table below.

Project Component	Product Description
Big Springs Submodel	Calibrated high-resolution MODFLOW 6 submodel of the Big Springs area nested withing the SVIHM and associated development and operational documentation
Big Springs Submodel	Updated water budget for the Big Springs region with improved characterization of groundwater pumping, aquifer recharge, and spring discharge to Big Springs Creek
Big Springs Submodel	Scenario modeling results
Isotope Study	Isotopic and geochemical dataset characterizing springs across the Lake Shastina-Big Springs corridor and lake end-member samples
Isotope Study	Technical memorandum presenting analytical methods and source attribution findings
Isotope Study	Documented revisions to the SVIHM reflecting improved conceptual model of groundwater-surface water interaction along the Lake Shastina-Big Springs corridor
Seasonal Forecasting Tool	Operational seasonal forecasting tool for the Shasta Valley watershed with user documentation
Seasonal Forecasting Tool	Technical memorandum documenting model development, predictor selection, validation results, and user guidance
Stakeholder Engagement Tools	Web-based interactive visualization tools presenting Shasta Valley groundwater data and model results for public audiences
Stakeholder Engagement Tools	Documented AI Agent available to the technical team for ongoing engagement tool development
All Tasks	All spatially explicit data and model outputs in GIS-compatible formats with FGDC-compliant metadata

Project Component	Product Description
Dissemination	Participate in at least one Reclamation-sponsored webinar upon request

C.4 Quality assurance and quality control. All project components will follow established QA/QC practices appropriate to their respective methodologies. For the Big Springs Submodel, model development and calibration will follow standard groundwater modeling protocols, including independent review of model inputs and calibration targets by a modeler not directly involved in model construction. Calibration performance will be evaluated against quantitative metrics, and all field-collected data will be screened for outliers and inconsistencies prior to use. For the isotope study, LLNL will apply its established laboratory QA/QC protocols for environmental tracer analysis, including the use of procedural blanks, duplicate samples, and certified reference standards for all analytical methods. Chain of custody documentation will be maintained from sample collection through laboratory analysis. Results will be cross-checked for internal consistency across the multi-tracer dataset and evaluated against published reference values for the region. For the seasonal forecasting tool, model development and validation will follow the QA/QC framework of Kouba and Harter (2024), employing statistical validation methods to assess model skill, guard against overfitting, and verify predictive accuracy. Predictor selection will be documented transparently to allow independent replication, and all code and analytical scripts will be version-controlled and reviewed by a second team member prior to finalization. All project deliverables will be reviewed by a senior technical staff member, and all technical memoranda and reposts will undergo internal peer review prior to submittal. Data will be archived in documented, open formats consistent with the project's data management practices described in Section 6.

C.5 Project partners, roles, and stages of engagement. The Siskiyou County Flood Control and Water Conservation District is the lead applicant and primary project sponsor. The District will provide overall project oversight, facilitate access to basin monitoring data and field sites, coordinate stakeholder engagement activities, and serve as the end user of all project deliverables. LWA serves as the primary technical contractor and will lead all hydrologic modeling work, including development of the Big Springs Submodel, adaptation and calibration of the seasonal forecasting tool, and integration of project findings into the SVIHM. LWA will also lead the AI-assisted stakeholder engagement tool development and provide overall project management and reporting support. LWA has been deeply involved in groundwater sustainability efforts in the Shasta Valley since the development of the Shasta Valley GSP (adopted in January 2022) and has continued as the primary technical partner to the District through ongoing sustainability plan implementation activities. This deep familiarity with the basin's hydrology, stakeholder landscape, and management priorities makes LWA well-positioned to lead the technical work under this project. LWA will also assist LLNL in the field during the isotope study, helping to identify, access, and coordinate sampling sites across the basin.

C.6 Staff credentials and experience. The Larry Walker Associates project team has direct experience with the Shasta Valley Basin, the basin's groundwater model, and implementation of the state's groundwater law. Field staff are based at the firm's Yreka office, approximately 60 miles from the basin, enabling cost-effective field access. The team can proceed immediately upon award. All positions are filled; no additional staff selection or hiring is required.

C.7. Ability to proceed immediately. Yes. LWA's ongoing involvement in Shasta Valley sustainability plan implementation means that project context, data access, modeling infrastructure, and stakeholder relationships are already in place, allowing technical work to begin without delay. LLNL is similarly poised to begin the isotope study following a brief desktop planning phase to finalize sampling locations and seasonal timing.

Criterion D: Dissemination of Results (10 Points)

D.1 Dissemination to Western water managers and technology transfer plan. As the primary beneficiary, the District will integrate project deliverables directly into its ongoing sustainability plan implementation activities. Because all project components directly support sustainability plan implementation, progress updates and technical findings will be incorporated into the GSA's standard annual reporting and public dissemination structure. Results will also be communicated to basin stakeholders through the GSA's regular stakeholder engagement meetings and through the public-facing interactive visualization tools developed under the AI-assisted engagement task, which are specifically designed to make complex technical findings accessible to diverse audiences including agricultural water users, municipal representatives, tribal partners, and elected officials. Technical findings will additionally be shared with the Watermaster, irrigation districts, and other basin partners through the GSA's existing coordination structure. Progress updates will be reported to the District Board of Directors at regular public meetings throughout the project period.

D.2 Communication internally and with partners and stakeholders. All project data, model files, and analytical scripts will be archived in open, documented formats and made available upon request. Any project reports or technical memoranda will be publicly accessible with sufficient methodological documentation for other agencies to evaluate the approaches. The isotope study results will similarly be made available to other agencies and researches working on similar aquifer systems. The project team will participate in at least one Reclamation-sponsored webinar upon request.

D.3 Availability to other water managers in the West and likelihood of adoption. The team will present findings at relevant professional conferences such as the Groundwater Resources Association of California. The improved understanding of the Upper Klamath volcanic aquifer system has direct technology-transfer value to neighboring basins and to other Western water managers working in volcanic terranes.

Criterion E: Presidential and Department of Interior Priorities (20 Points)

E.1 Improving Oversight in Federal Grantmaking (Executive Order 14332). This project is designed to deliver concrete, measurable scientific outcomes with transparent documentation and clear accountability for the use of federal funds, consistent with E.O. 14332. All project deliverables are documented in open, reproducible formats that allow independent verification of methods and results, and the project team is committed to compliance with reporting requirements throughout the grant period.

E.2 Artificial intelligence for water management and public engagement (OMB M-25-21, Secretarial Order 3444). This project incorporates AI and machine learning technologies as primary elements in two distinct and substantive ways, directly advancing the Federal Administration's priorities for AI deployment in Federal programs as articulated in OMB M-25-21 (Accelerating the Use of AI through Innovation, Governance, and Public Trust) and S.O. 3444 (Leading Interior's Path to Artificial Intelligence Transformation).

First, the Big Springs Submodel will employ machine learning-based calibration, using neural network regression to solve the groundwater model inverse problem identifying the aquifer parameter sets that best reproduce observed conditions from a large ensemble of model runs. This approach has demonstrated strong performance in calibrating MODFLOW models in complex hydrogeological settings (Baalousha, 2025; Montoya, 2020), substantially reducing the computational burden of traditional calibration while improving reliability in heterogeneous systems. The application of ML to federal water resources modeling represents a concrete implementation of AI to improve the efficiency and accuracy of federally supported science.

Second, the project will deploy AI agents as a productivity tool for the technical team to develop interactive, browser-based stakeholder engagement visualization tools. These agents ingest complex project datasets and assemble them into navigable, publicly accessible interfaces that require no specialized software or technical background to use. This application of AI directly improves the transparency and accessibility of federally supported water management science, making technical findings available to a broad public audience. The AI agents developed under this project will also remain available to the technical team as an ongoing resource, extending the benefit of this Federal AI investment beyond the project period.

E.3 Secretarial strategic objectives (Secretarial Orders 3417, 3418, 3419) and DOI Strategic Plan alignment. S.O. 3419 directs the Department of the Interior to take immediate steps to reduce living costs for hardworking American families. The Shasta Valley basin presents a direct and compelling connection to this priority. For these disadvantaged communities, reliable and affordable access to water is not an abstract resource management question but rather a direct cost-of-living concern. Groundwater is the sole drinking water source for municipal and domestic users throughout the basin, and water supply disruptions or uncertainty translate directly into economic hardship for families already operating with limited financial resilience. By improving the quantitative foundation for water management decisions and reducing the uncertainty that leads to reactive, disruptive management outcomes, this project supports the reliable, affordable delivery of water to some of the most economically vulnerable communities in rural northern California.

E.4 Water management and operational flexibility in Reclamation States. The Shasta Valley basin is located in California, a Reclamation State, and this project directly supports improved water management and enhanced operational flexibility for the basin's agricultural, municipal, domestic, tribal, and environmental water users. The Big Springs Submodel, seasonal forecasting tool, and isotope study collectively provide water managers with better information about when and where water is available, how the system responds to drought, and how management actions in one part of the basin affect other users. The seasonal forecasting tool in particular addresses the challenge of anticipating basin behavior weeks to months in advance, giving managers the lead time needed to make proactive rather than reactive water management decisions. While the Shasta Valley is not in the Colorado River Basin, the water management challenges it faces such as snowmelt dependence, drought vulnerability, competing demands among multiple use types, and the need for anticipatory management tools are broadly representative of conditions across Reclamation States in the western United States.

Criterion F: Cost Share Priority (5 Points)

The associated Budget Narrative and Form 424a provide a breakdown of the project budget as well as sources of matching funds and requested federal funds. Several sources of non-federal funds are available for matching as summarized below:

$464,500 (Non-Federal Funding) / $844,500 (Total Project Costs) = 55%

8. Environmental and Cultural Resources Compliance

The Project consists of data compilation, numerical modeling, water quality sampling at existing well and surface water locations, and software development. It involves no construction and no ground disturbance. The Project will not impact the surrounding environment with no impact to air, water, or habitat. Although Shasta Valley provides habitat for various species, the Project involves only monitoring and analysis and will have no effect on listed or proposed threatened or endangered species or critical habitat. Wetlands and surface waters subject to Clean Water Act jurisdiction exist within the basin, but the Project involves only monitoring and analysis at these features and will not affect them. The Project does not involve a water delivery system or any irrigation delivery system. No buildings, structures, or features listed or eligible for the National Register of Historic Places will be affected, and no archaeological sites will be disturbed, as the Project involves no ground disturbance. The Project will not affect Tribal lands or sacred sites and will not contribute to the introduction or spread of noxious weeds or invasive species.

9. Required Permits or Approvals

Permit / Approval	Applicable?	Compliance Plan
National Environmental Policy Act	Likely categorical exclusion	Coordinate with Reclamation; the Project involves no ground disturbance
Endangered Species Act, Section 7	Not anticipated	No effect to listed species from monitoring and analysis
National Historic Preservation Act, Section 106	Not anticipated	No ground disturbance; coordinate with Reclamation if required

Permit / Approval	Applicable?	Compliance Plan
Clean Water Act, Section 404	Not applicable	No dredge or fill
Clean Water Act, Section 401	Not applicable	No discharge
CA Fish and Game Code Section 1600	Not applicable	No streambed alteration
California Environmental Quality Act	To be confirmed	Monitoring and study activities are typically exempt

10. Letters of Support

Can provide if awarded

11. Letter of Partnership (Category B Applicants Only)

N/A – Category A Applicant

12. Overlap or Duplication of Effort Statement

The proposed work does not overlap with or duplicate any ongoing or planned efforts in the Shasta Valley region.

13. Conflict of Interest Disclosure

There are no conflicts of interest related to this project to disclose.

14. References

Baalousha, H.M. Machine Learning-Driven Calibration of MODFLOW Models: Comparing Random Forest and XG Boost Approaches. Geosciences 2025, 15, 303. https://doi.org/10.3390/ geosciences15080303

Kouba, C. and Harter, T.: Seasonal prediction of end-of-dry-season watershed behavior in a highly interconnected alluvial watershed in northern California, Hydrol. Earth Syst. Sci., 28, 691–718, https://doi.org/10.5194/hess-28-691-2024, 2024.

Montoya, S. (2020). *Machine Learning Supported Groundwater Model Calibration with Modflow, Flopy, PySal and Scikit Learn.* Hatari Labs. https://hatarilabs.com/ih-en/machine-learning-supported-groundwater-model-calibration-modflow-pysal-and-scikit-learn-tutorial