COLORADO
Colorado Water Conservation Board
Department of Natural Resources

Last Updated: August 2023

Colorado Water Conservation Board
Water Plan Grant – Statement of Work

Statement Of Work	
Date:	**December 2023**
Name of Grantee:	**Colorado State University (T.K. Gates and A. A. Andales)**
Name of Water Project:	**Colorado South Platte River Basin Salinity Characterization Study**
Funding Source:	

Water Project Overview:

Existing and emerging evidence suggest that portions of Colorado's South Platte River Basin (SPRB), like many other intensively irrigated stream-aquifer systems worldwide (Hopmans et al 2021; Wallender and Tanji 2012), suffer from salinization of water and land resources. Salt buildup poses a serious problem to agro-environmental systems, threatening the long-term productivity and sustainability of irrigated agriculture as well as municipal water supplies and other uses. Beyond the concentrating of solutes in applied waters that occurs by evaporation and transpiration, intensive irrigation and fertilization of alluvial soils can accelerate the rate at which geogenic salts and other mineral pollutants (e.g., selenium and uranium) are dissolved into alluvial aquifers that interact with rivers. This results in elevated salt concentrations that lower the quality of river flows that are diverted for irrigation and for other uses further downstream and threatens the ecological health of the riverine environment. Moreover, excess irrigation and canal seepage can lead to shallow saline water tables under cropped lands where evaporative up-flux accelerates soil salinization and depresses crop yields.

Many water users and managers agree that the nature, degree, and effects of salinity in the SPRB need to be better understood within the agricultural, environmental, and water-supply contexts. There are several related issues of concern to such stakeholders that have been identified:

- the spatial and temporal patterns in salinity and its chemical composition in streams, groundwater, and soils across the whole basin;
- the relative contribution to river salt loading and concentrations from treated municipal effluent point sources compared to that from agricultural return flow nonpoint sources;
- the severity of the salinity impact on soils and productivity from the 700,000 acres of valuable crop land in the SPRB;
- the effects of expanding sprinkler irrigation and the partial curtailment of well pumping by the Colorado Division of Water Resources (CDWR) on shallow groundwater and soil salinity;
- the long-term impact of recharge ponds for well augmentation situated throughout portions of the basin on subsurface and surface water salinity;
- the influence of salinity on municipal water supply and on water/wastewater treatment;
- the implications of dissolved salts to aquatic life in the stream network;
- the potential of alternative land and water management strategies to lower salt loads and concentrations; and
- the economic costs and benefits of salinity management.

Here we propose a project designed to fill in the data needed to allow the above issues to be adequately addressed. Clues derived from previously existing information suggest that high concentrations of salts in streams and groundwater, along with salt damage to land and crops, are indeed significant in the basin, increasing downstream. Still, further problem characterization needs to be conducted using well-designed and coherent data collection and analysis. *The proposed project would address the following research questions: (1) Just how severe and variable is salinization of water and land resources across the SPRB? and (2) where and how should further investigation be focused to refine understanding of the problem and to support a search for solutions?* Although there is presently a lack of peer-reviewed salinity studies in the SPRB, information and local expertise are nevertheless sufficient to guide the launch of a coherent probe of actual field conditions. A systematic field investigation, based upon an understanding of the existing data adequacy and gaps, will enhance the current state of knowledge of the salinity issue, will illuminate the urgency of the problem, and will clarify the need for additional data collection.

The project put forward here is envisioned as part of a multi-year research effort consisting of a problem characterization stage followed by a search for solutions stage (Figure 1). The aim of this three-year Phase 1 of the problem characterization tage is to build off previously existing information in the SPRB to design and embark on a coordinated field data collection effort to better describe and define the salinity problem in relation to issues identified in collaboration with stakeholders. Data to be collected and analyzed will include groundwater depths and salinity, salt concentrations and loads in streams and canals, and soil salinity. Analytical and statistical methods will be applied to the gathered data to (a) gain a preliminary sense of the nature of salinity and its severity in relation to beneficial water uses within representative regions across the basin, and (b) to determine the need for additional and refined field data to adequately characterize the salinity problem.

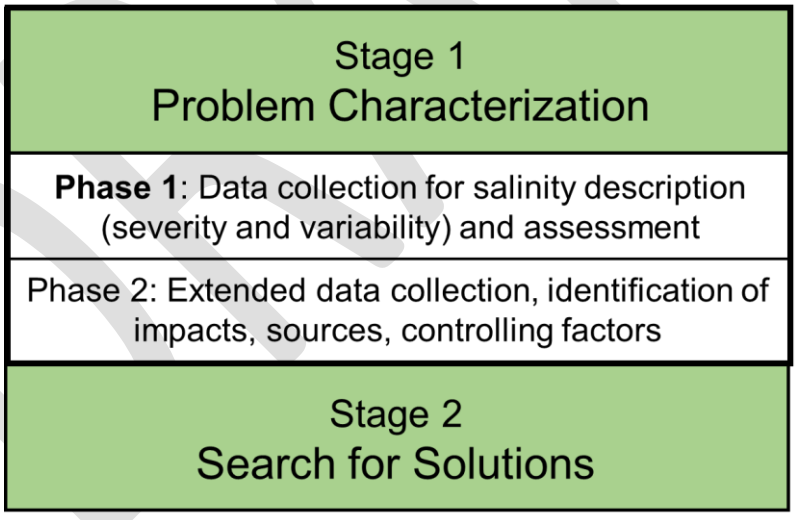

Figure 1. Components of the research effort needed to understand and solve salinization in the SPRB, with this project being Phase 1 of Stage 1.

Our *hypothesis* for Phase 1 is that *salinization in the SPRB is indeed serious, with severity increasing downstream, and that it warrants further study*. If evidence from this phase indicates this to indeed be the case, data collection will be expanded to better define the pattern of the problem over the entirety of the basin in a later Phase 2 of the problem characterization stage. This broader endeavor would entail gathering additional proximal (ground-level) data but also would make use of remotely-sensed data to permit cost-effective routine large-scale tracking of salinity levels across the SPRB. Attention also will

be needed to clarify the major *impacts* and to identify major *sources and controlling factors* of salinity. The resulting description of salinity conditions will form a baseline reference point and a platform for a systematic search for solutions, which is the next major stage in the research effort.

The degree of success of this project will depend upon collaboration with many agencies and partners. Concerns about the apparent salinity problem in the water and land of the SPRB led to the formation in 2020 of the South Platte Salinity Stakeholder Group (SPSSG) (> 35 members), which is being coordinated by the Colorado Water Center (CoWC). We have interacted with this group over the course of the last 2.5 years and the proposal outlined here incorporates many of their interests. An integral part of this project will be close interaction with the SPSSG who will provide regular input and guidance. An important initial step will be an identification by the SPSSG and other experts of salinity issues of greatest priority.

This proposal is submitted to the Colorado Water Plan Grant program as an *agricultural project*. It addresses the serious water quality issue of salinity with a special focus on irrigated agriculture, which markedly is influenced by and in turn influences the whole watershed. Thus, the project serves the interest of two Water Plan action areas: *robust agriculture* and *thriving watersheds*. From a broader perspective, the collaborative tasks outlined below are concerned with the following Colorado Water Values: (a) a productive economy; (b) a strong environment with healthy watersheds, rivers, streams, and wildlife; and (c) an informed public with solutions that are sustainable and resilient to changing conditions.

Summary of Previous Related Efforts

A literature search has uncovered only two peer-reviewed papers directly addressing salinity in the stream network of Colorado's Lower South Platte River. Gomez-Ferrer et al (1983) describe total dissolved solids (TDS) concentrations and salt loads along four river reaches between Henderson CO and Julesburg CO using data from 1965 – 1979. They report average total dissolved solids (TDS) concentrations near Kersey CO that were influenced by upstream irrigation return flows and ranged from about 700 mg/L to 1200 mg/L over 1975 - 1979. Concentrations near Julesburg CO over the same period were reported as 1100 mg/L to 1600 mg/L. These concentrations are classified as having moderate restriction for irrigation (Ayers and Westcot 1985). Recently, Hocking and Bailey (2022) used data from a variety of sources, including the Colorado Agricultural Chemicals Groundwater Protection Water Quality Database, in a salt mass balance model to simulate monthly average TDS concentrations in Colorado's South Platte River over 2002 – 2006. The average simulated concentrations over April – October of these years across urban and agricultural reaches of the river are about 400 mg/L and 1150 mg/L, respectively. Reported maximum simulated concentrations downstream near Julesburg CO are about 1700 mg/L. The model did not account for salt dissolution from geology or for reactive transport. The authors conclude that urban return flows, including both wastewater treatment plant effluent and road salt, play a major role in downstream salinity concentrations.

The US Geological Survey (USGS) published a technical report describing water quality over 1993 - 1995, including longer-term salinity trends over 1963 – 1996, in the SPRB at locations in Colorado, Nebraska, and Wyoming (Litke and Kimbrough 1998). Three additional technical reports (Wilson et al 2006, Johnson et al 2009, Neirbo Hydrogeology 2020) have been published after the year 2000, along with a PhD dissertation (Haby 2011) and an MS thesis (Hocking 2021). Collectively, these studies reveal average TDS concentrations increasing along the river from about 600 mg/L near Henderson to about 1300 mg/L near the CO-NE Stateline. Calcium and sulfate are reported as the major salt ions in waters of the agricultural region. The studies also indicate that total annual salt mass load in the river increases from Denver to Kersey and then decreases from Kersey to the Stateline, suggesting a net salt deposition to agricultural lands and to the underlying shallow aquifer. Strange et al (1999) express concern about high salinity in the South Platte River being stressful to some aquatic species but do not cite specific data.

Continuous monitoring of TDS, at selected stream locations in the SPRB currently is being carried out by the USGS and by Northern Water.

Refereed articles describing groundwater levels and salinity in the SPRB have not been discovered. However, limited available data suggest saline shallow groundwater conditions in some areas that are potentially hazardous to irrigated agriculture. Several reports have been issued over the last 60 years describing measured groundwater levels in the alluvial aquifer. Extensive analysis by USGS of data gathered from 1,669 wells over 1953 – 2012 (Wellman 2015) indicates shallow groundwater levels within 3 m (10 ft) of ground surface in about 30% of the wells and within 1.5 m (5 ft) in about 10%. Only 25% of the measured wells are dedicated monitoring wells, the remainder being irrigation wells which typically are measured only at the beginning and end of the irrigation season. Data on salt concentrations (including major ions) in the alluvial aquifer are much more limited, derived from early USGS technical reports by Bjorkland et al. (1957) and Smith et al. (1964), followed more recently by a report of a two-year study by Bruce and McMahon (1998). These limited studies show TDS concentrations averaging about 2,000 mg/L in the shallow alluvium, being much higher in some regions, and increasing downstream along the river valley. A more recent technical report by Northern Water summarizes specific conductance measurements in 43 monitoring wells over the period 2001 – 2006, indicating an associated average TDS of about 1,600 mg/L. Data are accessible from the Colorado Agricultural Water Quality Database maintained by the Colorado Department of Agriculture (CDA).

A key issue that has received very little attention to date is the interrelationship between salinity in the alluvial stream-aquifer environment and salinity on the irrigated agricultural lands where crop productivity is vulnerable. Narrative evidence of soil salinization has been increasing over recent years, like that in a recent article in *Fresh Water News* (2019) which points to salt crusts on agricultural fields near Sterling, CO. A technical report published by Northern Water (Wilson et al 2006) describes sampling in 36 irrigated fields over 2003 – 2005 to estimate soil water saturated paste extract electrical conductivity (EC_e), an indicator of soil salinity. Results show that the average measured EC_e value exceeded 1.7 dS/m (about 1,200 mg/L) in 64% of the surveyed fields and was above 2.5 dS/m in 47% of the fields. For comparison, threshold values to prevent crop yield damage for corn and alfalfa, which are broadly grown in the SPRB, are 1.7 dS/m and 2.0 dS/m, respectively. Vegetable crops like beans, carrots, and onions, which are important cash crops in the SPRB, can tolerate only about 1 dS/m in the soil EC_e.

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Project Objectives:

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The objectives of this project are:

(1) To gather new field data to better characterize groundwater, stream, and soil salinity for the purpose of addressing identified issues of concern in representative regions of the SPRB, and

(2) To process and synthesize the field data to (a) describe the severity and variability of salinity across the SPRB and (b) design additional data collection for further salinity characterization and assessment.

Task 1

Based Upon Existing Information and Identified Issues, Collect First-Phase Field Data on Salinity

Description of Task:

A first-stage data collection effort will be designed and implemented. Data on water and land salinity will be gathered at field sites in seven study regions of the SPRB (Figure 2). These study regions were designated based upon similarities in location along the stream network, soils, subsurface geology, and other factors. A coherent methodology will be used within and among the regions to obtain information that sheds light on the extent and severity of salinization.

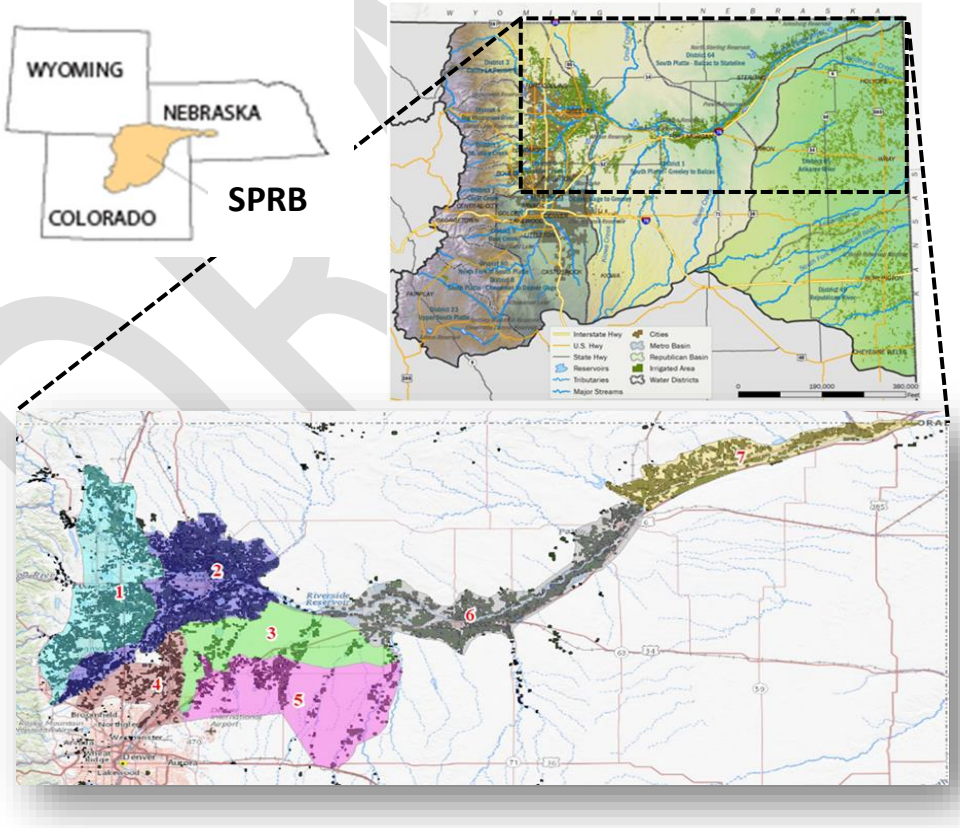

Figure 2. Map of the SPRB (above), and map of the proposed seven study regions in the Colorado SPRB (below). *Sources: USGS Colorado Water Resources Center (left) and Colorado Water Plan, CWCB (right).*

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Method/Procedure:

An extensive compilation of previously existing documents, databases, and models addressing SPRB salinity issues is being carried out by an on-going companion project funded by the Colorado Agricultural Experiment Station (CAES). Information compiled by these projects will be analyzed and interpreted in view of the salinity-related issues highlighted by the SPSSG and other experts. Based on this information, reconnaissance field visits will be made to verify, further assess, and document (e.g., via photos, GPS tagging, notes) salinity-affected areas identified in past studies and to locate new monitoring sites. Sites will be selected within each of the seven study regions of the basin. Site selection will be guided by statistical considerations and by GIS database queries and surveys for areas with similar soil textures, irrigation methods, water sources, cropping patterns, remote sensing (RS) spectral response (e.g., using multispectral images from Landsat and Sentinel satellites and algorithms based on vegetation indices), etc. Interviews also will be conducted with farmers, stakeholders, and experts to guide site selection.

A field data collection effort at the selected field sites will obtain important water and land data. This work will be coordinated with the companion CAES project and with projects funded by Colorado Corn (CC) which have initiated similar tasks related to Phase 1 data collection. Consistent methodology will be applied at multiple representative sites to provide coherent information to adequately answer the research questions. Results are intended to either affirm or deny the value of investigating the issue further in a Phase 2 and in a subsequent search for solutions stage. In designing Phase 1, as well as the later Phase 2, of salinity characterization, we will consider landowner interest and permission, stakeholder input, cost, personnel constraints, and statistical guidelines in light of uncertainty (Sanders et al 1983; Smith, Schwartz, Alexander 1997; Strobl, Robillard et al 2006). Methods for storing, managing, and accessing data will be addressed.

Describing the nature of saline shallow water tables, caused in part by irrigation deep percolation and canal seepage, is important to understanding waterlogging and capillary upflux of salt into the crop root zone. A total of 15 groundwater monitoring wells already have been installed in study regions 2, 6, and 7 by the CAES and CC projects in summer 2023 and another 5 to 10 are planned for summer 2024. Groundwater monitoring wells will be installed by the proposed project at an additional 15 to 20 sites across regions 1 – 7. The wells will be drilled at a distance below the water table and equipped with PVC pipe (5-cm ID), bentonite sealant, and concrete pad. Each well will be permitted by the State of Colorado, will be equipped with a water level logger to monitor water table depth, and will provide access for periodic reading of water quality parameters (EC, pH, temperature, oxidation reduction potential) using roaming In-Situ Aqua Troll multiprobe devices and for collecting water samples. About half of these new monitoring wells also will be equipped with calibrated EC data loggers. To validate water level loggers, routine manual readings of water table depth and water quality parameters will be taken three times during the irrigation season (May – October) and twice during the non-irrigation season (November – April). Ground water samples will be collected from each well three times during the irrigation seasons and twice during the non-irrigation seasons using a filtered low-flow sampling technique. Samples will be analyzed in the laboratory to determine major cations and anions and TDS. This will permit calibration relationships between EC and TDS to be developed. Data on water table depth also will be obtained from dozens of wells routinely monitored by CDWR and CDA through an agreement with these agencies. EC measurements with data loggers, periodic measurements of other water quality parameters, and periodic sampling for TDS and salt ion concentrations will be made in about 10 to 15 of these CDWR and CDA wells, rendering a total of 25 to 35 new groundwater monitoring wells in which salinity data will be gathered.

Multiprobe instruments also will be used for measuring water quality parameters at about 40 locations in streams, irrigation canals, and drains across the representative regions. At a representative subset of these locations, filtered water samples for salt ion analysis also will be gathered three times during the irrigation seasons and twice during the non-irrigation seasons using a peristaltic pump. At 5 to 10 sites

that are in proximity to key stream gaging locations in the South Platte River and tributaries, operated by CDWR and USGS, EC dataloggers will be placed in stilling wells to gather data for use in computing salt mass loading. Sites will be included near selected points of urban wastewater effluent discharge as well as near key diversion stems for urban water supply.

Agricultural fields, within the area of influence of the groundwater monitoring stations, will be surveyed during the irrigation season of the first year of the project with electro-magnetic induction (EMI) instruments (e.g., EM38-MK2) for field-based and regional mapping of the electrical conductivity of the saturated soil extract (EC_e) (Morway and Gates 2012). Within each sampled field area, dozens of GPS-positioned readings of bulk soil EC (EC_a) will be taken. The calibration of the EC_a data will be carried out in comparison with EC_e data obtained from laboratory analysis of soil samples. Soil samples for this calibration will be gathered at multiple depths at an average of about 8 to 10 sites within each 20 to 30-acre sampled field area, guided by the Electromagnetic Sampling Analysis and Prediction (ESAP) and t-ANOCOVA procedures (Lesch et al 2002). Samples obtained from the fields also will be analyzed in the laboratory for soil water content, texture, bulk density, and major ion composition.

Records will be kept of irrigation methods and water sources for the studied field sites. Crop yield estimates will be gathered from farmers and may also be measured at selected sites within fields using crop cuttings if time and budget permit. This information will shed light on the severity of measured salinity levels (EC_e) in relationship to impact on crop yields.

Deliverable:

Field data elements on groundwater salinity, surface water salinity, and soil salinity at locations across the SPRB, along with available information on contributing factors, will be gathered and archived in a GIS database for mapping with the use of an online dashboard, and will be summarized in a final project report. The online dashboard is part of the South Platte River Basin Salinity website hosted by the Colorado Water Center at CSU (URL).

Task 2

Analyze and Interpret Data to Describe the Severity and Variability of Salinity.

Description of Task:

Analytical and statistical methods will be applied to the data collected in Task 1 to initially map and assess the extent of water and land salinization in the SPRB. Information from the literature and from stakeholders and experts will be used to gauge the severity of the measured salinity levels, namely the degree to which beneficial water uses are damaged.

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Method/Procedure:

The data gathered in Task 1, along with the data compiled and collected by the companion CAES and CC projects, will be used to gain preliminary insight into the salinity status of water and land within the selected representative regions of the SPRB.

The GIS database platform will be used to analyze and represent previously available data on factors that influence salinization spatially over the basin. This will include soil properties (i.e., soil texture, depths, soil layering, soil slopes and infiltration capacity/rates), water supply sources, stream networks and flows, groundwater aquifer characteristics, cropping patterns, irrigation methods, geology, long term weather variables (on air and soil temperature, rainfall, relative humidity, solar radiation, wind speed), and selected satellite-based multispectral remotely sensed images from Landsat satellites. Sources of data for the GIS database will include USDA-NRCS SURGO, COAGMET, Northern Water, USDA ARS, USDA National Agricultural Statistics Service (NASS), water districts, USGS EarthExplorer, and Planet Lab, along with the data gathered in Task 1. Data quality and reliability will be assessed, and information gaps will be identified. Levels of uncertainty in the data will be estimated based upon considerations of measurement error and system variability.

The GIS database also will be queried to visualize the data compiled and gathered by this project in Task 1 on groundwater salinity, stream salinity, and soil salinity. Information on acceptable levels of salinity for different beneficial uses in the watershed (crop production, water supply, aquatic life) will be compared to measured levels of salinity to assess *severity*. GIS will display the varying magnitude of salinity from location to location and GIS analytical tools will be used to explore trends, patterns, degree of *variability*, and relationships among basin properties and these salinity variables.

Deliverable:

Analysis of preliminary field data will provide a clearer picture of the magnitude and composition of salinity in relation to location within the SPRB, and of just how serious and widespread current salinity problems likely are. This will provide signposts for the path forward toward enhanced characterization of the issue. Information obtained from preliminary field data, along with previously existing data, will form the basis for Task 3 which will focus on planning the collection and analysis of further data.

Task 3

Integrate Results and Design the Second Phase of Salinity Characterization.

Description of Task:

This task uses the data gathered and analyzed in Tasks 1 and 2, along with previously existing information, in preparing Phase 2 of salinity monitoring to further refine characterization of the salinity problem within the representative regions of the SPRB to permit an adequate answer to the research questions posed about severity and variability.

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Method/Procedure:

The data gathered and analyzed in Tasks 1 and 2, along with compiled previous information, will be assessed to note gaps in records, identify potential salinity hot spots in the SPRB, extrapolate data to unmonitored areas with estimates of uncertainty, and determine priority sites and timing for additional data collection.

The information gathered within the GIS database platform under Task 2 will be explored and results will be used to identify areas of the SPRB for scheduling additional sampling at the existing sites of Task 1 and for locating extra monitoring sites for groundwater/stream/soil salinity sampling that will encompass a wider range of field conditions. Additional field sites will be selected within the seven representative regions designated in Task 1. To determine the number and location of additional monitoring sites, two approaches will be implemented: (a) evaluation of preliminary distributed salinity levels estimated from both previously existing data sources and from measurements made in Task 1, and (2) GIS spatial interpolation and extrapolation using analytical and statistical tools, such as kriging, following methods like those outlined in Bradai et al. (2016) and Eldeiry and Garcia (2011, 2012). New data elements also may be deemed necessary for collection at existing and new locations.

Deliverable:

A blueprint will be laid out based upon a strategy for acquiring a more comprehensive understanding of the severity and variability of salinity over the entire SPRB in a Phase 2 of the problem characterization stage of this WP grant effort. Estimated costs and scheduled duration of tasks will be included in the plan.

A final report will describe collected data, preliminary assessment of the severity and variability of salinity in SPRB, and a plan for further data collection and analysis in Phase 2.

Budget and Schedule

This Statement of Work shall be accompanied by a combined Budget and Schedule that reflects the Tasks identified in the Statement of Work and shall be submitted to CWCB in excel format.

Reporting Requirements

Progress Reports: The applicant shall provide the CWCB a progress report every 6 months, beginning from the date of issuance of a purchase order, or the execution of a contract. The progress report shall describe the status of the tasks identified in the statement of work, including a description of any major issues that have occurred and any corrective action taken to address these issues.

Final Report: At completion of the project, the applicant shall provide the CWCB a Final Report on the applicant's letterhead that:

- Summarizes the project and how the project was completed.
- Describes any obstacles encountered, and how these obstacles were overcome.
- Confirms that all matching commitments have been fulfilled.
- Includes photographs, summaries of meetings and engineering reports/designs.

The CWCB will pay out the last 10% of the budget when the Final Report is completed to the satisfaction of CWCB staff. Once the Final Report has been accepted, and final payment has been issued, the purchase order or grant will be closed without any further payment.

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Payment

Payment will be made based on actual expenditures and must include invoices for all work completed. The request for payment must include a description of the work accomplished by task, an estimate of the percent completion for individual tasks and the entire Project in relation to the percentage of budget spent, identification of any major issues, and proposed or implemented corrective actions.

Costs incurred prior to the effective date of this contract are not reimbursable. The last 10% of the entire grant will be paid out when the final deliverable has been received. All products, data and information developed as a result of this contract must be provided to as part of the project documentation.

Performance Measures

Performance measures for this contract shall include the following:
(a) Performance standards and evaluation: Grantee will produce detailed deliverables for each task as specified. Grantee shall maintain receipts for all project expenses and documentation of the minimum in-kind contributions (if applicable) per the budget in Exhibit C. Per Grant Guidelines, the CWCB will pay out the last 10% of the budget when the Final Report is completed to the satisfaction of CWCB staff. Once the Final Report has been accepted, and final payment has been issued, the purchase order or grant will be closed without any further payment.
(b) Accountability: Per Grant Guidelines full documentation of project progress must be submitted with each invoice for reimbursement. Grantee must confirm that all grant conditions have been complied with on each invoice. In addition, per Grant Guidelines, Progress Reports must be submitted at least once every 6 months. A Final Report must be submitted and approved before final project payment.
(c) Monitoring Requirements: Grantee is responsible for ongoing monitoring of project progress per Exhibit A. Progress shall be detailed in each invoice and in each Progress Report, as detailed above. Additional inspections or field consultations will be arranged as may be necessary.
(d) Noncompliance Resolution: Payment will be withheld if grantee is not current on all grant conditions. Flagrant disregard for grant conditions will result in a stop work order and cancellation of the Grant Agreement.

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

Colorado Water Conservation Board

Water Plan Grant
Budget and Schedule

Prepared Date: October 24, 2023

Name of Applicant: Timothy K. Gates and Allan A. Andales (Colorado State University)

Name of Water Project: Colorado South Platte River Basin Salinity Characterization Study

Project Start Date: July 1, 2024

Project End Date: June 30, 2027

Task No.	Task Description	Task Start Date	Task End Date	Grant Funding Request	Match Funding	Total
1	Collect first-phase field data on salinity	7/1/2024	12/31/2026	$ 215,859.58	$ 126,134.00	$341,993.58
2	Analyze and interpret data to describe the severity and variability of salinity	10/1/2024	1/31/2027	$ 123,867.69	$ 30,177.00	$154,044.69
3	Integrate results and design the second phase of salinity characterization	10/1/2026	6/30/2027	$ 52,243.81	$ -	$52,243.81
	Indirect Cost (IDC) Base (excludes tuition) =	$510,101.92				
	IDC (15% of IDC Base)			$76,515.29		$76,515.29
			Total	$468,486.37	$156,311.00	$624,797.37