A Decision Support Tool to help Water Managers in the Colorado River Basin in Utah

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Abstract

As populations in the Western U.S. continue to grow, the need for clean and accessible water grows as well. Little can be done to increase water supply from nature, but changes in management decisions and infrastructure may help ensure each drop of water is purposefully used. This paper focuses on the development of the Utah Colorado River Accounting and Forecasting – Decision Support Tool (UCRAF-DST) to help assess both water budgets (supply, consumptive use, losses, etc.) and water rights for the Colorado River Basin (CRB) in Utah. The UCRAF-DST has three main components: data collection and processing, depletion-runoff calculator, and RiverWare model(s). Using the RiverWare modeling system as the computational hub, the UCRAF-DST implements high-resolution canal, field, and evapotranspiration rates (OpenET) to accurately account for consumptive use calculations. Losses due to conveyance (e.g., lined vs. unlined canal), application method (e.g., sprinkler vs. flood irrigation), and irrigation efficiency (e.g., overspray, surface runoff, etc.) are calculated at the field-level and then aggregated to the canal-level before inclusion into RiverWare. The overall goal of the UCRAF-DST is to develop a comprehensive understanding of current water rights and water usage at the HUC-8 basin-scale for the CRB in Utah and to create a planning tool to evaluate how changes (e.g., crop types, irrigation methods, water reduction methods, water right transfer, curtailment, etc.) affect water availability and water rights. This knowledge can then be used to make water management decisions that ensure sustainable water resources within the CRB of Utah.

This paper focuses on the current implementation of UCRAF-DST for the Duchesne River Basin in Utah, which was chosen as the proof of concept for this project for multiple reasons, including the high use of water for both municipal (Strawberry Aqueduct and Collection System) and irrigation purposes.

Introduction

Water in the Western United States is often a scarce commodity exacerbated by drought. Settlers coming to Utah in the mid-1800's realized quickly that irrigation systems were needed to grow crops and built extensive irrigation networks (Arrington & May, 1975). Typically, those who first beneficially used water resources were entitled to continue to use those resources, a system typically referred to as the Doctrine of Prior Appropriation. This system remains to this day in Utah with the State Engineer being the administrative officer of water rights, with most of the water right rules/procedures codified in Utah Code Title 73 (Utah Code Title 73, 1997). Sustained droughts as well as continued population growth in Utah is putting pressure on the limited water resources (Courtenay et al., 2018). This pressure results in continued calls to improve water management to ensure every drop of water is beneficially used for agriculture, municipal, and environmental demands. Realizing the complicated nature of water resources and water law, the Colorado River Authority of Utah (CRAU) was established by the State of Utah in 2021 with a mission to protect, conserve, use, and develop Utah's Colorado River system interests. The Utah Colorado River Accounting and Forecasting – Decision Support Tool (UCRAF-DST) was proposed as a method to help CRAU assess water budgets/water rights for the Colorado River Basin (CRB) in Utah. The main goal of UCRAF-DST is to develop a comprehensive understanding of current water rights and water usage at the Hydrologic Unit Code (HUC) 8 basin-scale for the CRB in Utah and to create a planning tool to evaluate how changes (e.g., crop types, irrigation methods, water reduction methods, water right transfer, curtailment, etc.) affect water availability and water rights.

Work on UCRAF-DST began in July 2022. This paper will focus on the overall concept and methods of UCRAF-DST as well as the initial results in capturing the water usage at the canal-scale, which are then aggregated to the basin-scale.

Methods/Results

Two phases were proposed to complete the Duchesne River Basin pilot of the UCRAF-DST. Phase 1 focuses on the initial development of each component previously listed (i.e., data collection and processing, depletion-runoff calculator, and RiverWare model). The goal of Phase 1 is to ultimately understand the current water budget and usage of water rights within the Duchesne River Basin. Phase 2 will focus on applying the UCRAF-DST to determine how changes within the Duchesne River Basin (e.g., water right acquisition, changes to irrigation practices, changes to conveyance systems, etc.) affect water budget and water rights. Although Phase 1 and Phase 2 will be discussed in this paper, only preliminary results for Phase 1 will be shown and discussed.

Phase 1. Understanding of Current Water Balance and Water Budget in the Duchesne River Basin.

Figure 1 provides a schematic of required data, processes, and the calculations within Phase 1. The Rhoades Canal (Figure 2) is one of the first irrigation canals along the Duchesne River and will be used to demonstrate step-by-step calculation of the water expected to irrigate the fields supplied by the canal. The connection of data to the RiverWare model is shown in Figure 1 as well. RiverWare was chosen for the UCRAF-DST due to the ability to account for water budgets and water rights, and its use in similar water operation models (Coors, 2006; Sterle et al., 2020).

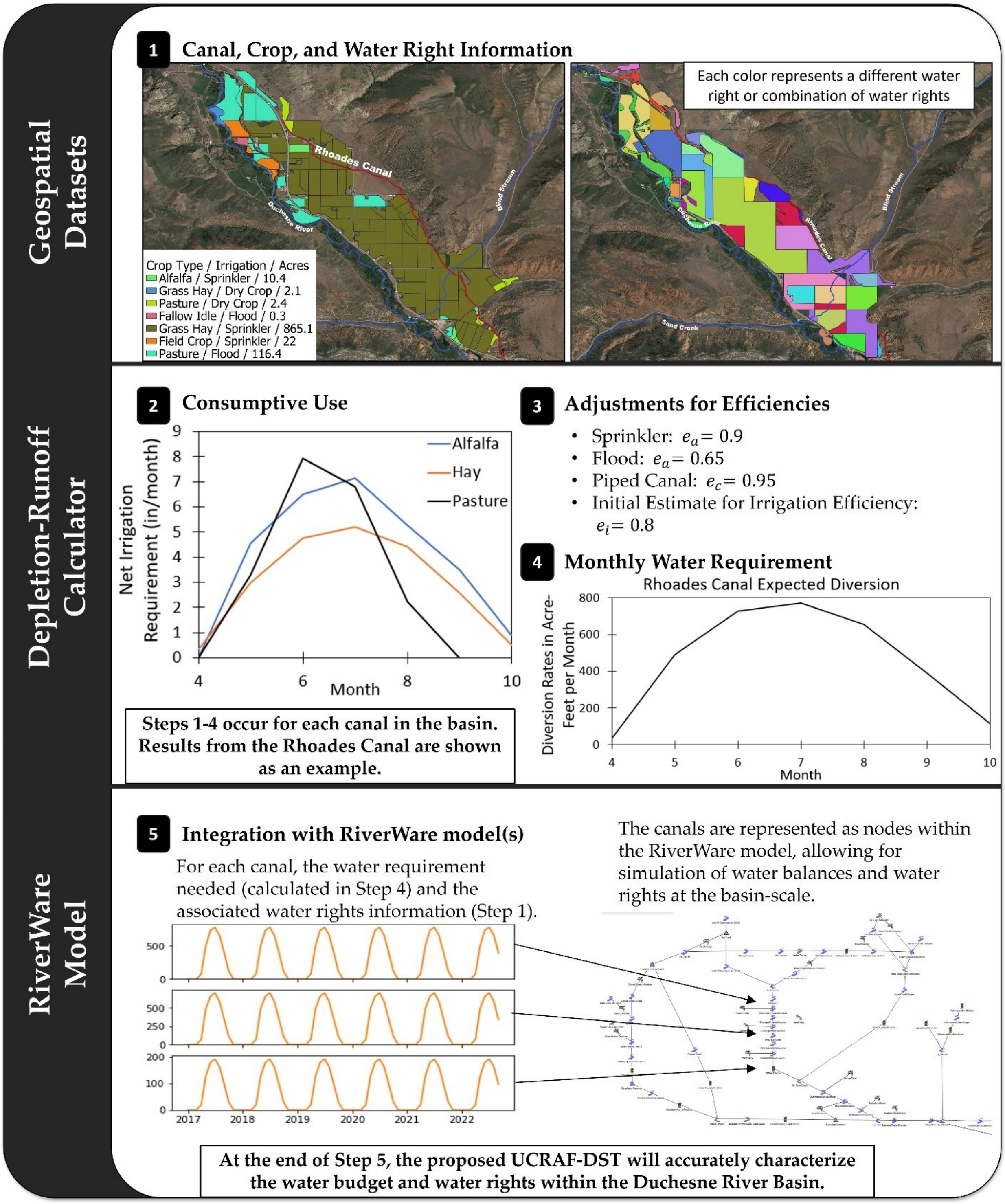

Figure 1. Schematic of the data and processes needed to complete Phase 1. All calculations and efficiencies (e) in Steps 1-4 are based on GIS analysis and on Equation 1 (see step-by-step calculations below). The calculations are shown on a monthly timestep from April-October for the Rhoades Canal, one of the first irrigation canals along the Duchesne River.

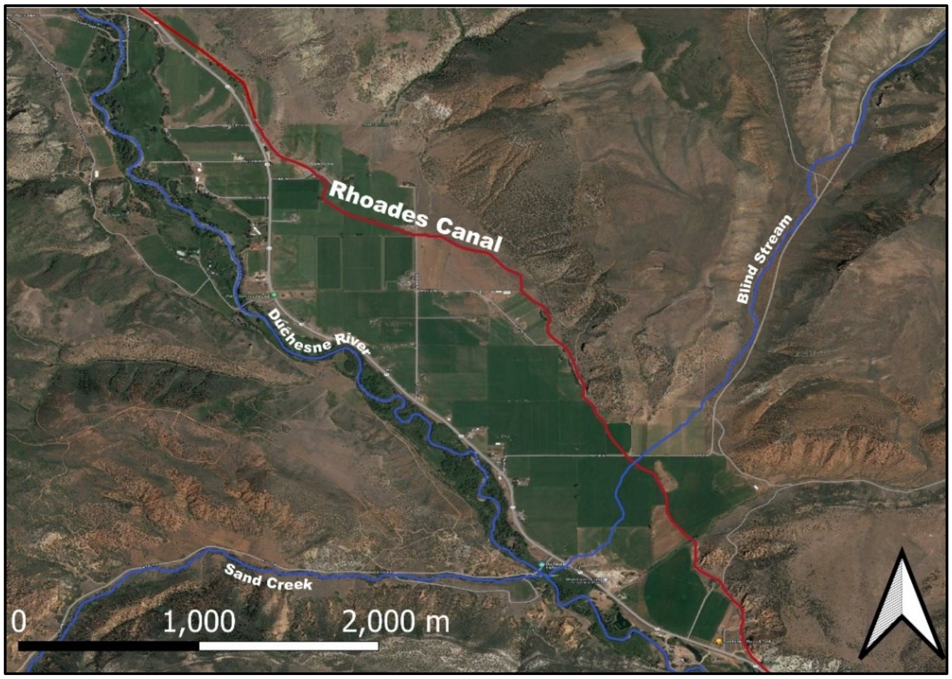

Figure 2. Rhoades Canal, located at approximately 40.45°N 110.81°W in northern Utah, approximately 95 km East of Salt Lake City, UT.

Steps associated with Figure 1:

1. Geographic Information System (GIS) is used to determine irrigatable areas supplied by each canal, crop type, irrigation method, water rights associated with each field, and canal characteristics.
    a. Water rights data is provided in geospatial format by the Utah Division of Water Rights (UDWR) (https://opendata.gis.utah.gov/datasets/utahDNR::utah-place-of-use-irrigation/explore?location=39.471338%2C-111.581749%2C-1.00). The water rights associated with each field are also available from UDWR (https://maps.waterrights.utah.gov/EsriMap/map.asp and https://www.waterrights.utah.gov/asp_apps/wrprint/wrprint.asp?wrnum=43-1709). The UDWR data also associates each field with the canal that is supplying the water, in this case the Rhoades Canal. For lands irrigated by the Rhoades Canal, there are 41 different water rights with priority dates ranging from 1906 to 1964.
    b. The crop type and irrigation method for each field are provided by the Utah State Land Cover dataset in a Shapefile format (https://gis.utah.gov/data/planning/water-related-land/). For fields irrigated by the Rhoades Canal, the acreage associated with each crop / irrigation method are shown within Figure 1.
    c. The length of each canal is determined from the USGS NHDPlusHR dataset which provides shapefiles with the location and names of stream reaches and canals (https://apps.nationalmap.gov/downloader/#/). The canal type (e.g., earthen canal, lined canal, pipe, etc.) was determined from aerial imagery and site visits. The Rhoades canal is a pipe.
2. Consumptive use based on crop type.
    a. In general, evapotranspiration is considered the main contributor to consumptive use in agricultural applications. Here, the consumptive use would be the

evapotranspiration from the crops minus the effective rainfall that typically occurs.

i. In Utah, consumptive use is calculated for a variety of crops throughout the state, with the location of the calculations corresponding to weather stations (Hill, 1994).
ii. OpenET (Melton et al., 2021) is a relatively new dataset that will be used in future versions of the UCRAF-DST to calculate consumptive use.

b. Here, we use consumptive use estimates derived from (Hill, 1994) (https://www.waterrights.utah.gov/techinfo/consumpt/i0074.htm) to determine the monthly consumptive use for all crops irrigated by the Rhoades canal. Hill (1994) calculates a consumptive use estimate for each month, but the values do not change from year to year.

3. Set efficiency coefficients for the canal, crops, and irrigation methods.
   a. Water conveyance and irrigation methods are not 100% efficient. Therefore, loss in efficiency is determined using efficiency coefficients based on Hoffman et al. (2007):
      i. Water Conveyance (e_c) – lined vs. unlined vs. pipe canals
      ii. Water Application (e_a) – sprinkler vs. flood irrigation
      iii. Soil Water Storage (e_s) – based on soil type (initially assume e_s=1)
      iv. Irrigation Efficiency (e_i) – surface runoff, overspray, etc. (initially assume e_i=0.8)
      v. Deep Percolation Ratio (DP_r) – losing water to aquifer (initially assume DP_r=1)
      vi. Tailwater Ratio (TW_r) – water lost permanently to tailwater (mainly a concern in flood irrigation; initially assume TW_r=1)
4. Calculate the monthly water requirement for the canal.
   a. The water required to irrigate a field (Q_f) is dependent on evapotranspiration (ET), the crop coefficient (K_c), the effective precipitation (P_e), and the efficiency of the irrigation system. In general, Q_f can be estimated by:
      i. Equation 1. $Q_f = \left((ET * K_c) - P_e\right)/(e_c\, e_a\, e_s\, e_i\, DP_r TW_r)$
         1. $\left((ET * K_c) - P_e\right)$ represents the water needed for a healthy crop, which is calculated in Step 2.
         2. The efficiency of the irrigation system ($e_c\, e_a\, e_s\, e_i\, DP_r TW_r$) is determined in Step 3.
   b. By summing all calculated water requirements for fields serviced by an individual canal, the total water required by that canal can be calculated. Because the depletion rates for each crop type (Hill, 1994) are monthly, the water requirements for the canal are also presented in a monthly timestep (units of acre-feet of water per month).
5. The water requirements for each canal are then input as timeseries datasets into the RiverWare model. Water rights information (priority date, use rates, etc.) associated with the fields serviced by each canal are also input into the RiverWare model.
   a. Only limited development of the RiverWare model for the Duchesne basin has occurred as part of UCRAF-DST. More information on the ability of RiverWare to simulate water budgets and water rights allocations are available on the RiverWare website: https://www.riverware.org/.

Several water users within the Duchesne River Basin fund a real-time flow measurement system at several of the canals within the Duchesne River basin (http://duchesneriver.org/). Observed flow data for 6 canals that are fed by the Duchesne River were obtained from the website. The calculated water requirement within each canal was tested against observed flow rates at these 6 canals along the mainstem of the Duchesne River basin. As can be seen in Figure 3, the simulated water requirements match well with the water actually delivered to each of the canals. It is of note that the simulated water requirements do not change year-to-year because the Hill (1994) dataset does not change from year-to-year. Replacement of the consumptive use tables in Step 2 with OpenET data may result in more variation between years for the simulated water requirements.

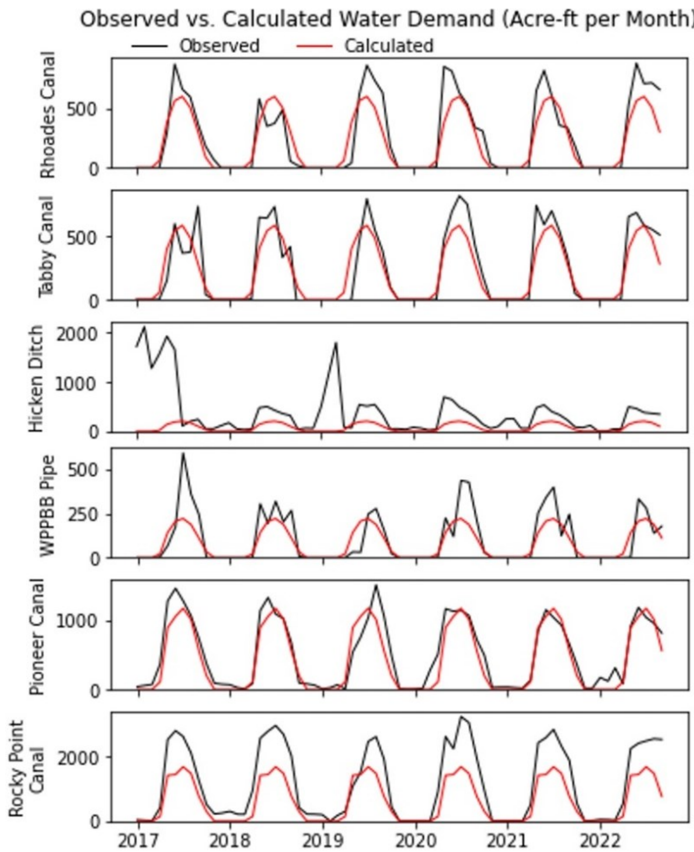

Figure 3. Observed and calculated water demand (acre-feet per month) for six canals along the Duchesne River. Observed flow rates from gaging stations were used to calculate the observed monthly water demand. The calculated water demand came from completing Steps 1-4 in Figure 1 for each of the canals.

At the end of Phase 1, UCRAF-DST will accurately characterize the current water budget and water rights usage within the Duchesne River Basin. The characterization of the current water budget and water rights usage will serve as the baseline condition for Phase 2.

Phase 2. Evaluating how changes made to the Duchesne River Basin affect the Water Budget and Water Rights.

Phase 2, scheduled to begin in October 2023, builds upon work completed under Phase 1 and will focus on using the UCRAF-DST to evaluate how prospective changes (e.g., water rights acquisition, changes to irrigation practices, changes to conveyance systems, etc.) impact the water budget and water rights within the basin. Figure 4 provides a schematic of user input (depicted by knobs at top of figure) and required development efforts within Phase 2. The knobs represent changes to the underlying datasets that will then be used in the UCRAF-DST. For instance, a change from flood irrigation to sprinkler irrigation for a field will change the e_a value from 0.65 to 0.9, thus resulting in less water needed to irrigate the field. That savings of water would be translated to the canal, and therefore to the RiverWare model for simulation of water budget and water rights. Similarly, fallowing a field would change the irrigation requirement for the canal that once serviced that field, which would again reduce the water requirement for the canal and result in changes to the water budget and water rights within the RiverWare model.

Because Phase 2 focuses on analyzing prospective future changes within the basin, two simulations will be run each time a potential change is made: 1.) a baseline analysis of the system (Phase 1) if no changes were made; and 2.) a modified analysis showing changes to water budget and water rights under the changed scenario. The user will have the option to define the timeline for the analysis, whether historical (i.e., evaluating if change was made over the past 20 years) or statistical (i.e., evaluating if change is made now under multiple climate scenarios).

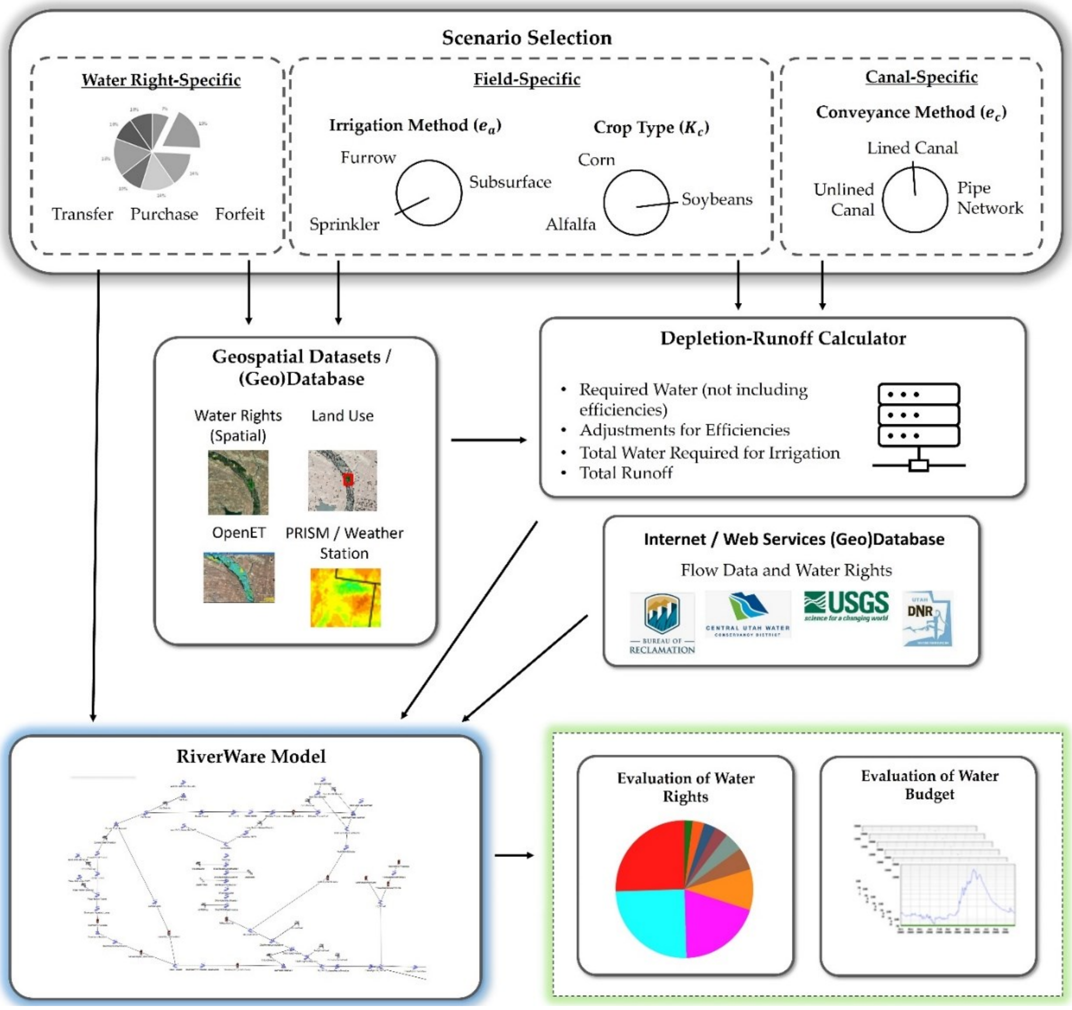

Figure 4. Phase 2 concept of the UCRAF-DST to evaluate how potential changes (e.g., crop types, irrigation methods, water reduction methods, water right transfer, curtailment, etc.) within the basin will affect the water budget and water rights within the basin.

Because Phase 2 of the project has not started at the time of this publication, no preliminary results are available.

Conclusions

Water management will play a key role in the future of the western United States, both for municipalities and for agriculture. This paper describes the current development of the Utah Colorado River Accounting and Forecasting – Decision Support Tool (UCRAF-DST) to help assess both water budgets (supply, consumptive use, losses, etc.) and water rights for the Colorado River Basin (CRB) in Utah, with a focus on the pilot study in the Duchesne River Basin (a subbasin within the CRB). Using GIS and real-time data, UCRAF-DST is able to evaluate the water requirements of an irrigation system at the canal-scale, while accounting for the efficiencies of getting the water from the river to the crops (e.g., water losses due to canal type, irrigation method, etc.). This paper showed that the calculated water requirements at the canal-scale matched well with the observed flow data within the canals over a six-year period. The water requirements for each canal are then input as timeseries datasets into the RiverWare model. Water rights information (priority date, use rates, etc.) associated with the fields serviced by each canal are also input into the RiverWare model. Although not fully implemented, it is anticipated that the RiverWare model will use the canal-level water requirements and water rights data to assess the water budget and water rights for the Duchesne River Basin, which is the goal of Phase 1 of the project. Phase 2, scheduled to begin in October 2023, builds upon work completed under Phase 1 and will focus on using the UCRAF-DST to evaluate how prospective changes (e.g., water rights acquisition, changes to irrigation practices, changes to conveyance systems, etc.) impact the water budget and water rights within the basin.

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