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Planning for Idaho's waterscapes: A review of historical drivers and outlook for the next 50 years

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ABSTRACT

Water availability and use are increasingly critical factors determining the resilience and vulnerability of communities in the Western United States (US). Historical water availability and use in the state of Idaho is synthesized by considering the biophysical drivers of climate and surface runoff alongside human drivers of land-use, hydrologic engineering and state water management and policies. Idaho has not experienced chronic water scarcity in the last half century, particularly in comparison to neighboring states to the south. An outlook of water availability and use in Idaho for the next half century is developed that accounts for projected changes in population and climate. The magnitude of annual runoff is not expected to change substantially across much of Idaho, yet the timing of surface water availability is likely to change due to earlier snowmelt and reduced summer surface water availability. We posit that Idaho is well positioned to make institutional and policy decisions that secure its own water resources in the face of changing environmental conditions and resource-based water demands.

1. Introduction

In the next 50 years, will the State of Idaho, United States, be able to sustain significant population growth, expand its economy, and protect the landscapes and ecosystems functions that make the state such an attractive place to live? Many coupled human-environment systems in Idaho centered on issues of water resources are being impacted by population growth, land-use change, and climate change. Idaho has been among the fastest growing states in the past decade (Sheridan, 2007; Smutny, 2002; Travis, 2007), relies heavily on snowmelt runoff for agricultural productivity and energy production (Hamlet and Lettenmaier, 1999; Hamlet, 2011), and has seen substantial declines in spring snowpack over the past century (e.g., Mote et al., 2005, 2018). Continued changes in these drivers of state-level water resources in the coming half-century are reasoned to impact Idaho's waterscapes (Tohver et al., 2014). Waterscapes refer to water in all of its forms in the landscape from a systems perspective and includes physical processes governing water availability and social processes affecting water use and consumption.

Idaho has long recognized the need for an organized system to distribute water. Like other western states with limited water supplies, Idaho adopted the doctrine of prior appropriation (Slaughter, 2004). The availability, distribution, and use of water remains the single most critical factor for sustainable economic development across semi-arid lands of the western U.S., including the state of Idaho (e.g., Grey and Sadoff, 2007). Implicit in this factor is the need to adapt Idaho and the western states' water management and policy suites (e.g., Mayer and Greenberg, 2000; Nielsen-Pincus et al., 2010; Sridhar and Nayak, 2010; Tang et al., 2012) to changing conditions.

This paper examines how Idaho's waterscapes have evolved and adapted historically, and how these waterscapes are likely to continue to evolve into the future in a regional context. We first provide context

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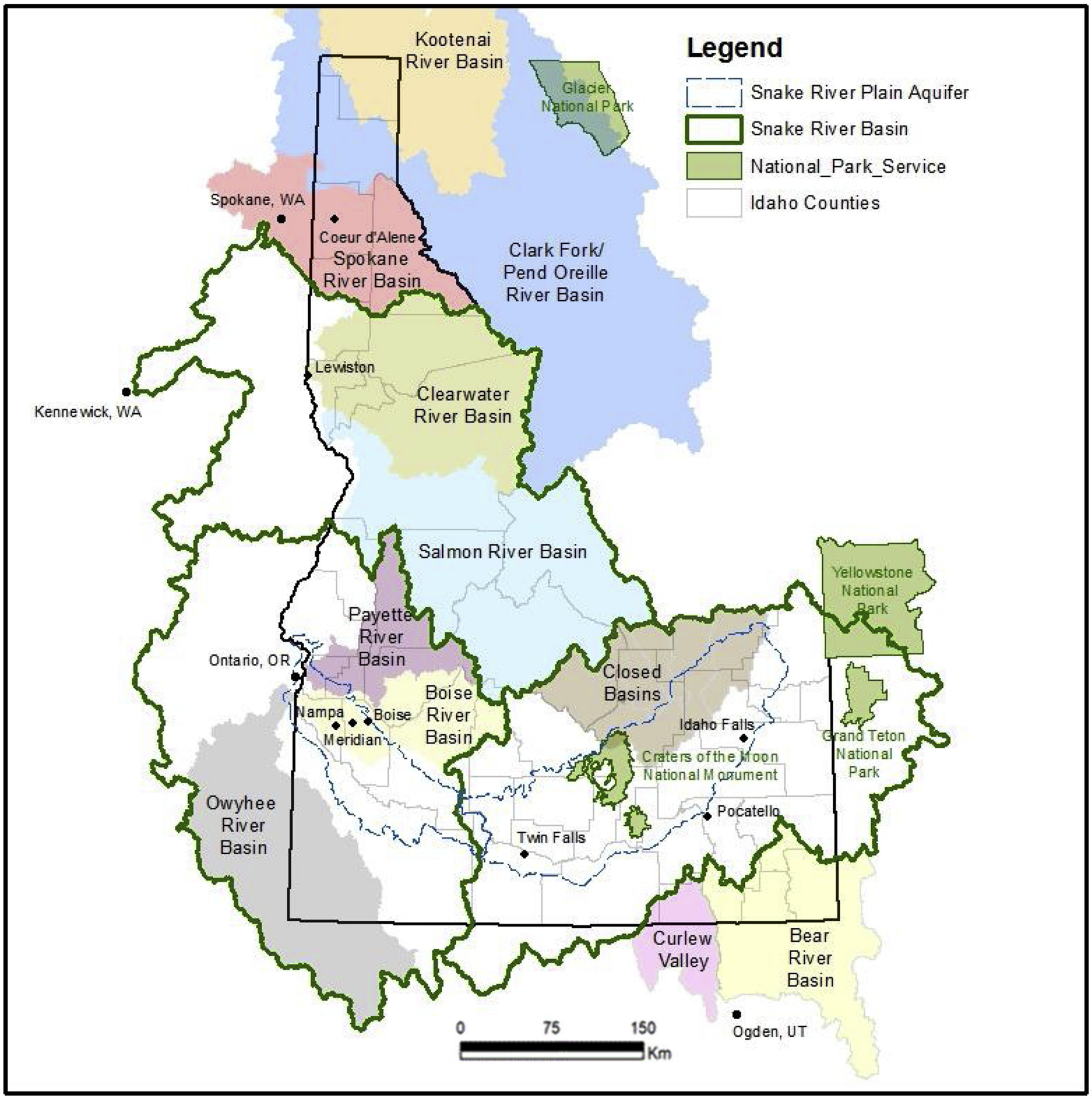

Fig. 1. Map of Idaho showing major river basins, groundwater (aquifers), and population centers.

for contemporary waterscapes in Idaho by reviewing both the water resource development, including infrastructure, institutions, and policy, as well as climate drivers and patterns of surface and groundwater diversions. Through this context we then project water availability over the next 50-years and discuss the potential consequences of changes to water resources within the state. We discuss future water availability and use in the context of Idaho's relationship with adjacent Western states, since water markets are potentially adaptive institutions addressing freshwater stress in the neighboring states. Finally, we explore two scenarios for future water use and conservation in Idaho as a tool for considering key water management issues that will be of particular importance to Idaho's waterscapes during the next 50 years.

2. The current state of water availability and use in idaho

Idaho lies on the western flanks of the North American continental divide and is characterized by diverse ecological and climatological zones. These include mountainous temperate inland forests of north and central Idaho, most of the semi-arid Snake River Plain, and a portion of the Great Basin in the south-east corner of Idaho (Fig. 1).

2.1. Idaho's river basins

The majority of Idaho's landmass occupies the headwaters of the Columbia River or its tributaries, and this dominates water resource development and management in Idaho. The Snake River watershed drains a broad swath of central and southern Idaho. This watershed extends from Idaho's eastern border with Wyoming, near Idaho Falls, to its western border with Washington State, at Lewiston (Fig. 1) and is underlain by the Eastern Snake River Aquifer, a fractured basalt aquifer that stretches across much of south central Idaho. The Salmon and Clearwater rivers and their tributaries drain the mountains of central Idaho from the Montana border on the east to their confluence with the Snake River in the west (Fig. 1). The Spokane, Pend Oreille, and Kootenai rivers drain the northern panhandle of Idaho as well as portions of western Montana and the Canadian province of British Columbia. These three rivers, all developed for regional hydropower production, are directly tributary to the Columbia River above Grand Coulee Dam. Grand Coulee Dam, which has no fish passage facilities, cuts off access for anadromous fish to the Upper Columbia Basin.

The lower Snake River basin, including the Clearwater and Salmon basins, is located mostly within the remote and lightly populated mountainous region of central Idaho and contains the only remaining habitat for anadromous fish in Idaho. The access of anadromous fish to historic habitat in the middle and upper portions of the Snake River basin were cutoff by the development of three hydropower dams in Hells Canyon. The middle and upper basins of the Snake River, which stretch across southern Idaho, have been heavily developed for agricultural and hydropower production. This portion of the Snake River basin contains the bulk of Idaho's human population and is seeing significant shifts in land-use and water resource demand from agriculture to domestic, municipal, and industrial economic sectors near population centers. The upstream location of the Snake River relative to the lower Columbia River basin has important implications with respect to the regional hydropower production, flood control operations, and preservation of remaining anadromous fish populations (Miles et al., 2000;BPA (Bonneville Power Administration), 2008). For example, Idaho Power Company and the Army Corp of Engineers coordinate the operation of Brownlee Reservoir and Dworshak Reservoir for flood control operations for the lower Columbia River and the Nez Perce Agreement of 2004 guaranteed that water from the middle and upper Snake River basins would be released to augment flows in the lower Snake River during periods when anadromous fish are migrating out to the ocean (Vonde et al., 2016).

2.2. Hydroclimate

Approximately 75% of the statewide annual precipitation occurs from Nov-May during which storm tracks bring Pacific mid-latitude cyclones across the northwestern US. Mean annual precipitation across Idaho exhibits strong geographic variability from over 3000 mm/year across the higher elevation windward slopes of the Bitterroot and Selkirk Mountains in central and northern Idaho, to less than 200 mm/year in the southwestern Snake River plain (Wise, 2012). The seasonal mismatch in precipitation and water use necessitates additional artificial water storage. Similar to other portions of the western US, much of the winter precipitation falls as snow over higher elevation mountains and is seasonally stored as snowpack and melts throughout the spring and into early summer providing runoff that generally satisfies summer water demands (Li et al., 2017). The timing of precipitation and amount of snowfall during winter, and the subsequent melt rate of the accumulated snow pack in the spring and early summer, plays an important role in determining the fraction of precipitation that runs off (e.g., Abatzoglou and Ficklin, 2017), as well as the quantity and seasonality of surface water.

Observed changes in climate across Idaho mirror those seen across the western United States featuring a long-term, although variable, warming of around 0.8 °C over the last century (Abatzoglou et al., 2014) and ambiguous changes in precipitation (Abatzoglou et al., 2014; Luce et al., 2013). In Idaho, these changes have culminated in reduced spring snowpack (Mote et al., 2018), particularly in lower-elevation watersheds that are most sensitive to temperature changes (Tennant et al., 2015; Klos et al., 2014). Since 1950 streamflow observations for unregulated basins across Idaho also have shown a one-to-two week advancement in the center of timing of runoff in snowmelt dominated watersheds (Stewart et al., 2005; Clark, 2010; Klos et al., 2014), and decreases in annual streamflow, annual minimum streamflow, and streamflow during the driest quartile of the year (Clark, 2010; Luce and Holden, 2009; Kormos et al., 2016). A combination of increased potential evapotranspiration due to higher atmospheric water demands and longer growing seasons, less precipitation falling as snow (Abatzoglou et al., 2014), reduced mountain precipitation (Luce et al., 2013), and changes in vegetation are hypothesized to have contributed to declines in streamflow.

Complementary to longer-term changes in the regional hydroclimate is substantial interannual to decadal variability that contributes to periodic drought and water scarcity. Large-scale modes of climate variability such as the El Niño Southern Oscillation (ENSO) influence precipitation and temperature variability across the interior Pacific Northwest encompassing the state of Idaho. For example, the canonical patterns of the warm phase of ENSO, or El Niño, include warmer than normal winter and spring temperatures, and below normal precipitation across the Rocky Mountains (Mote, 2003; Abatzoglou et al., 2014). Subsequently, El Niño winters often result in reduced spring snowpack, earlier snowmelt, and reduced summer streamflow. Retrospective consideration of regional hydroclimate indicates periods of marked hydroclimatic variability – including protracted drought conditions throughout the 1920s and 1930s as part of the broader 'Dust Bowl' drought (e.g., Wise, 2010). Likewise, recent droughts such as the 2015 'snow drought' that also impacted the Cascades and Sierra Nevada have also partially been attributed to natural climate variability (Mote et al., 2016; Abatzoglou and Rupp, 2017).

Precipitation that falls across the state in either liquid or solid form finds one of four outlets: 1) it infiltrates the surface and eventually enters the groundwater table, 2) it moves as runoff into the network of streams and rivers that ultimately feed into the Columbia River, 3) it evaporates from the top layer of soil or surface water, or 4) it is taken up by the land-atmosphere system through plant water use or evaporation, or collectively evapotranspiration (ET). The proportion of water following each of these routes is dependent upon climate, land use and land cover, soils and geology, and water engineering.

2.3. Land use and land cover

In Idaho, the federal government manages nearly 64% of the area of the state. The area of urbanization and rural development in Idaho is low relative to much of the US. Only 1.2% of the state is considered to be composed of 'impervious surface,' the descriptor used for paving and other anthropogenic development that inhibits percolation and infiltration processes and increases surface runoff (Paul and Meyer, 2001). In contrast, 36% of the state is forested, 44% is classified as rangelands (including both semi-arid grasslands and shrublands), 0.4% is surface water, 3.8% is classified riparian, and 11% is agriculture. Of the agricultural lands, two-thirds is irrigated agriculture (primarily in southern Idaho) while the remainder is dryland farming (primarily in north central Idaho). Over 24 billion m^3 of water was withdrawn in 2015 to irrigate 14,570 km^2 of land (Murray, 2018), primarily located in the Snake River Plain (USDA (United States Department of Agriculture), 2016).

The primary long-term land cover conversions in Idaho over the past century include converting rangelands (i.e., mixed shrublands) to irrigated agriculture, grassland prairie to dryland farming, forests, rangelands, and riparian zones to impervious surfaces (i.e., urbanization and development), forests to shrublands, and shrublands to grasslands (Pellant et al., 1990; Matheussen et al., 2000). Since the 1970s, 5% of irrigated land in parts of the Upper Snake River Basin have been converted to urban development (Baker et al., 2014). Decreases in irrigated cropland have continued in recent decades with a 13% decline in the Upper Snake River Basin from 2005 to 2015 (USDA (United States Department of Agriculture), 2016). Since land cover controls the rates of ET, interception and infiltration, anthropogenic land cover conversion can substantially alter the surface water budget (Allen et al., 2007).

2.4. Water engineering

Like many relatively arid states, Idaho has developed considerable infrastructure to store, divert, and transport water, as well as reduce flooding potential. The transformations to Idaho's rivers in the southern part of the state were part of the reclamation program that spread across the American West from the 1880s and in Idaho specifically from the 1900s to the 1970s catalyzed by the Carey Act of 1894 and the 1902 Reclamation Act (Worster, 1986; Wilkinson, 1992; Reisner, 1993; Grace, 2012; Lovin, 1987, 2002). Water resource infrastructure has specifically been developed for mining, hydropower generation, and for the storage and transport of water for agricultural purposes.

Water resource development in Idaho was initiated by the mining industry which utilized the doctrine of prior appropriation for water allocation (Worster, 1986; Grace, 2012). Water was essential in mining extraction, and diversions over long distances to where the lode was discovered were often necessary. Eventually mining would also lead to significant environmental degradation in a number of basins, for example, the Spokane River basin (Aiken, 1994; National Research Council, 2005). Initially hydropower was developed in Idaho in the late 19th and early 20th century to support energy needs for municipal, mining, and later agricultural development. Hydropower use requires water rights but are notably non-consumptive, returning the water to the river channel for other uses. Development of irrigated agriculture in the Middle Snake River Basin was initiated in the Boise Valley in the 1860s to support mining communities. Further expansion of surface water irrigation beyond the river valleys would lead to diversion schemes such as the development of Milner Dam on the Upper Snake River in association with the water right acquired in 1900 for the Twin Falls Canal Company. Once surface water resources were largely developed, irrigation expanded further into the Snake River Plain through groundwater development. The extraction of groundwater and improvement of irrigation efficiency for both the delivery and application of surface water led to significant declines in groundwater levels in many basins (Johnson et al., 1999; Kjelstrom, 1995). Decline of groundwater levels in the largest of Idaho's aquifers, the ESPA, is of particular concern. In the last decade both the Idaho Water Resource Board (IWRB) and some private entities have begun storage projects to support aquifer recharge. The decline of storage in the ESPA has been the focal point of numerous legal battles over water rights. The IWRB began a formal aquifer recharge program that mainly operates during the non-irrigation season and during the early irrigation season, when runoff is high enough to allow them to divert water under their very junior water rights.

2.5. Water consumption in Idaho and the Western US

Statewide consumptive water use in Idaho was 24.5 billion m^3 in 2015, of which 7.4 billion m^3 was from groundwater withdrawals (Murray, 2018), compared to total groundwater storage in the East Snake River Aquifer of approximately 300 trillion m^3. As of 2010 Idaho had the highest per capita statewide water use in the US and the second highest overall use for irrigation, behind California (USGS (United States Geological Survey), 2017a, 2017b). Nonetheless, there are other qualitatively significant non-consumptive water uses including hydropower (Markoff and Cullen, 2008; USDI (United States Department of the Interior Bureau of Reclamation), 2011), instream salmonid fisheries (Palmer et al., 2009; Isaak et al., 2012), and cultural values for Native American tribes (Slaughter et al., 2010) that contribute to a complex of water use needs.

An analysis of contemporary (1981–2000) consumptive water use (e.g., water removed from surface water or groundwater without return to the system) compared to runoff from precipitation in the 11 western US states (Moore et al., 2015) indicates that much of central and northern Idaho maintains a water surplus (consumption is lower than runoff) during each of the four seasons. In contrast, the Snake River plain mimics a pattern seen across much of the southwest where a water deficit (consumption exceeds runoff) begins each spring, intensifies in summer, and decreases in autumn (Fig. 2, Table 1). Statewide water deficits are observed in summer for California and Arizona, and to a lesser extent in Nevada and Utah.

Water withdrawals in Idaho have dropped moderately statewide since the 1980s (a 6.6 billion m^3 / year reduction from 1985 to 2015; USGS, 2017b) despite an increase in population of 623,500 in the same period (USCB (United States Census Bureau)., 2017) - this has relevance for future water use when considering the projected changes.

2.6. Water management and policy

Currently water management and policy in Idaho is governed by the desire to protect the state's sovereignty over its water resources and the need to manage the state's surface and groundwater resources conjunctively.

2.6.1. Water rights

Idaho, like much of the western US, allocates water according to a priority-based system, commonly referred to as *first in time, first in right* or *prior appropriation*. Water rights that were established for a legally allowable beneficial use, such as mining, irrigation, domestic, and hydropower were given a water right certificate that specifies the point of diversion, the type and place of use, and the priority date that the beneficial use of that water was established. The priority date determines the priority of water delivery during times of shortage when there is inadequate water to meet all users' rights. The user with the most senior right has the first priority of delivery. Idaho completed an extensive effort in 2014 to adjudicate all water rights in the Snake River basin (Strong and Orr, 2016).

2.6.2. The state water plan

Proposed *schemes* in the 1960s to divert the rivers of Idaho to other regions of the western United States led to early efforts by the state of Idaho to manage its water resources comprehensively through a state water plan. The 1976 State Water Plan set minimum streamflows at key gauges across the state to protect ecosystems, while also focusing on the continued development of water resources in the state, it foresaw the need for aquifer recharge programs, and a Water Supply Bank (IWRB, 1976). The guiding principle of the State Water Plan is optimal use of its water resources and state sovereignty: "*The State asserts sovereignty over the development and use of Idaho's water resources for the benefits of its citizens. Any action by the federal government or others states that would impair Idaho's sovereignty over its waters is against state policy*" (IWRB, 2012). The plan now accommodates greater flexibility in water resource management through an evolving definition of beneficial use, the need for mechanisms to allow water right transfers that involve change of use, change of timing, and the change of the point of diversion while preserving the priority of the right. The plan recognizes that the key to this flexibility is the enhancement of the Water Supply Bank through the exploration of more efficient processes to apply for water right changes.

2.6.3. Water banking

Idaho has two water banking programs that fall under the state's Water Supply Bank – a statewide water-banking system that allows for the transfer of surface and ground water rights and local rental pools that allow for the transfer of water between users within specified boundaries. Administered by the Idaho Water Resource Board, the Water Supply Bank has served as a facilitator of water exchange where water rights holders with excess water can connect with buyers who have unmet water demands (Cobourn et al., 2013), creating an economic incentive for the leasing of water that may otherwise go unused (Contor, 2009). Local rental pools implement the 'last fill rule' which requires that water uses for irrigation must be satisfied before all other uses, meaning non-irrigation water leases are filled last and are therefore at greater risk of not being allocated water in drought years. Water districts also determine a fixed price at which to lease water that does not fluctuate dependent on economic conditions, leaving less incentive for users to volunteer water during dry years (Clifford et al., 2004).

2.6.4. The swan falls agreement and the Snake River Basin Adjudication

The State Water Plan of 1976 attempted to memorialize a long-held water management policy for the Snake River that is referred to as the "two river system" (Strong and Orr, 2016; IWRB, 1976). The "two-river system" held that the Snake River above Milner would be developed

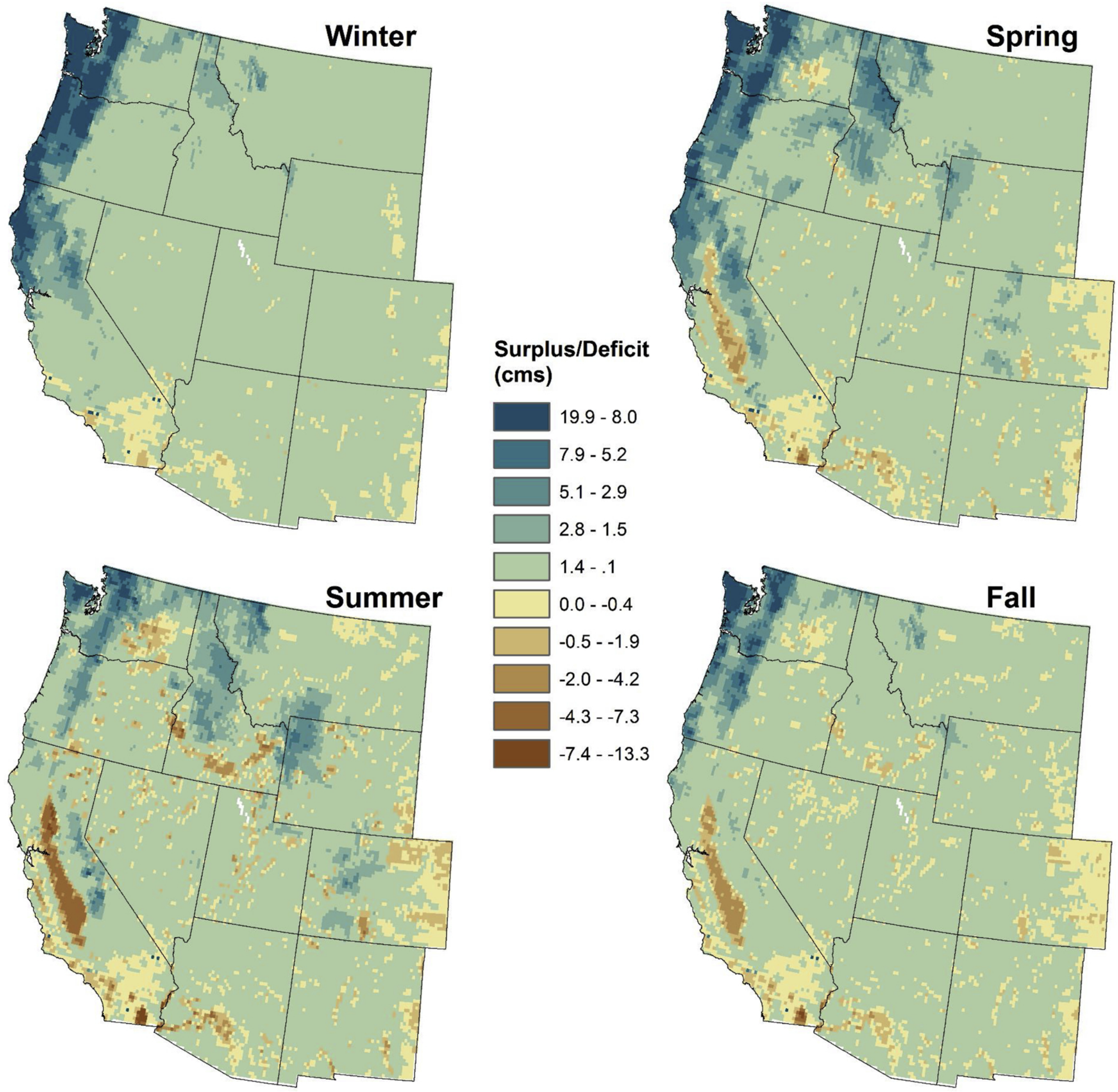

Fig. 2. Water surplus/deficit by season for the western US, based on the difference between runoff available and consumptive use, in cubic meters per second per square kilometre (1980–2000).

primarily for irrigation, while the Snake River below Milner would be used primarily for non-consumptive uses like hydropower generation and aquaculture (Strong and Orr, 2009; 2016). This two-river system was legally challenged in 1977, and following an Idaho Supreme Court ruling (Strong and Orr, 2016; Jones, 2016), a compromise was made: the Swan Falls Agreement. The Swan Falls Agreement required the state to carry out an adjudication of all water rights in the Snake River basin within the Idaho portion of the Snake River.

The Snake River Basin Adjudication (SRBA) resulted the adjudication of both surface and groundwater rights (Vonde et al., 2016) and in

Table 1
Annual average, winter (Dec-Feb), spring (Mar-May), summer (Jun-Aug), and fall (Sept-Nov) runoff (cubic meters per second) and surplus/deficit (defined as runoff – consumptive water use) (million cubic meters) for the eleven western states (after Moore et al., 2015) derived from USGS Stream Gauges (1980–2000).

State	Runoff (cubic meters per second)					State	Deficit/Surplus (Runoff- Consumptive Use) (million cubic meters)				
	Annual	*Winter*	*Spring*	*Summer*	*Fall*		*Annual*	*Winter*	*Spring*	*Summer*	*Fall*
AZ	182	240	254	123	113	*AZ*	2	17	8	−15	−3
CA	3,101	5,181	4,391	1,644	1,186	*CA*	179	436	306	−45	20
CO	695	273	965	1,170	371	*CO*	41	22	69	54	17
ID	1,864	1,188	3,097	2,292	880	*ID*	140	102	256	142	62
MT	1,532	918	1,982	2,278	951	*MT*	125	79	167	178	77
NM	208	145	283	264	139	*NM*	11	11	16	10	6
NV	452	309	701	573	224	*NV*	33	26	56	35	15
OR	3,783	6,364	4,740	1,680	2,346	*OR*	316	549	403	115	194
UT	483	293	689	651	298	*UT*	33	24	54	34	21
WA	5,173	7,210	5,766	3,681	4,035	*WA*	436	622	489	291	341
WY	791	323	895	1,495	451	*WY*	59	27	73	102	33

Table 2
Projected changes by 2040–2069 relative to late 20th century conditions (1971–2000) simulated by 10 different climate models using a "business as usual" emissions pathway (RCP8.5). Results presented are average of 10 different climate models and show annual changes. Population projections based on EPA estimates from SRES A2 scenario; value is mean change averaged from 2040 to 2069 (incl. standard deviation).

Watershed / River basin	Value for 10 models	Precipitation Change (%)	Temperature Change (°C)	Runoff Change (mm)	Population Change (%)
Statewide (210.2 mm)*	Average	+6	+3.73	−14.2	+22%
	Min / Max	(-1 to +16)	(+3.0 to +4.35)	(-31.5 to +11)	(+/- 4.3%)
Clearwater River Basin(471 mm)*	Average	+5	+3.59	−51.5	−39%
	Min / Max	(-1 to +10.5)	(+2.76 to +4.5)	(-84 to +15)	(+/- 6.9%)
Spokane River (533 mm)*	Average	+5.6	+3.57	−39.6	+13%
	Min / Max	(0 to +12)	(+2.77 to +4.5)	(-67 to +7)	(+/- 3.0%)
Snake River Basin(120 mm)*	Average	+7	+3.73	+0.7	+28%
	Min / Max	(-1.3 to +19)	(+3.0 to +4.26)	(-23 to +11)	(+/- 5.4%)
Salmon River Basin (294 mm)*	Average	+5	+3.67	−38	
	Min / Max	(-2.2 to +14)	(+2.8 to +4.4)	(-68 to +6)	

* Total annual average runoff for the basin historically.

the raising of minimum streamflows of the Snake River at Swan Falls Dam. Since completing the SRBA, Idaho has begun an adjudication of water rights in northern Idaho, within the Spokane, Coeur d'Alene, and Kootenai basins. During the adjudication a dedicated court was set up in Twin Falls to handle all water right issues related to the SRBA. The 2004 Nez Perce Agreement that issued out of the SRBA provided a mechanism for habitat restoration and dedicated storage water and some natural flow rights for the recovery of anadromous fish populations that had been devastated by habitat loss and dam construction throughout the Columbia River basin (IWRB, 2018). To reverse long-term declines in the Snake River's discharge, the Idaho Water Resource Board started a managed recharge program in 2009 (Vonde et al., 2016).

2.6.5. Aquifer management through state recharge and voluntary use reduction

At the time the IWRB's recharge program was ramping up, a water call by the Surface Water Coalition Delivery Call was made against groundwater pumpers. In 2015, faced with a trend of increasing mitigation requirements, a settlement agreement was reached between the Surface Water Users Coalition and the Idaho Groundwater Appropriators to end curtailment calls (SWC-IGWA, 2015). Groundwater pumpers agreed to decrease groundwater diversions annually, and surface water users agreed to support the tate's managed recharge program.

2.6.6. The Columbia river treaty

One of the most significant regional water challenges facing the Pacific Northwest is the review of the Columbia River Treaty and how flood-control will be managed after 2024 when the current flood control operations are set to expire (Krutilla, 2018). The Columbia River Treaty called for three large dams to be built in Canada as well as a dam in Montana on the Kootenai River. The focus of the initial treaty was hydropower and flood control. But with the initiation of the treaty review in 2018, additional concerns in regard to the goals of the treaty have stressed the importance of promoting conservation and regaining valuable ecosystem services, including the recovery of federally listed species (Cosens and Fremier, 2014).

3. Projected changes for Idaho

Future water availability in Idaho is a function of changes in both supply and consumption. Our objective in projecting future conditions is to highlight which contributors are likely to change the most during the coming decades, and how these changes will impact overall water availability in Idaho.

3.1. Water availability

3.1.1. Projections of runoff and water deficit

We used climate projections from 10 climate models participating in the Fifth Coupled Model Intercomparison Project (CMIP5) that credibly simulated historical climate across the broader region (Rupp et al., 2013). Daily output from these models was statistically downscaled using the Multivariate Adaptive Constructed Analogs method (Abatzoglou and Brown, 2012) using the historical gridded meteorological data of Livneh et al., (2013) at a ˜6-km spatial resolution. Climate model runs covered both historical forcing (1950–2005) and Representative Concentration Pathway (RCP) 8.5 experiments (post-2006). While other scenarios are equally plausible, we justify using a single scenario since inter-model variability exceeds inter-scenario variability for time horizons through the mid-21st century. Furthermore, assessing impacts to water resources associated with the larger rates of warming projected by RCP8.5 versus other scenarios is a more safeguarded approach for assessing risks to state water resources.

Meteorological data were used to force the Variable Infiltration Capacity (VIC, Liang et al., 1994) macroscale hydrologic model, which has been used extensively to model land surface hydrology across the US. Land surface runoff from VIC is routed to basin outlets using river routing routines to produce estimates of naturalized streamflow (e.g., Lohmann et al., 1998). We specifically examined streamflow outputs at four representative locations of main rivers: 1) Spokane River at Post Falls, 2) Clearwater River at Spalding, 3) Snake River near Weiser, and 4) Salmon River at White Bird. We considered only naturalized flows that exclude effects of diversions, reservoir or other storage, and man-made withdrawals from the system (Brekke et al., 2010). Although naturalized flows will not replicate flow in managed systems, the objective of these simulations is to provide baseline estimates of potential changes in volume and timing of streamflow across the state.

Climate projections for the northwestern US by the mid 21st century (2040–2069) show a substantial warming with nominal overall changes in annual precipitation (Rupp et al., 2017). Multi-model mean projections for the state of Idaho across the 10 climate models show a warming of 3.7 °C (3–4.3 °C, 10-model range) and a potential slight increase in annual precipitation of 6% (-1% to 16%, 10-model range) (Table 2). The models also tend toward a slight overall increase in winter and spring precipitation (< 10%) and decline in summer precipitation. However, the intermodel spread in projected change, small projected change relative to interannual variability, and potential inadequacies in capturing the influence of climate change in orographic precipitation efficiency (e.g. Luce et al., 2013) collectively suggest low confidence in significant changes in overall precipitation. The subsequent impacts to surface hydroclimate across the region include decreased snowpack, shorter snow accumulation season, earlier snowmelt, and increased ET leading to likely decreased streamflow and heightened stress for water resources during the summer months (e.g.,

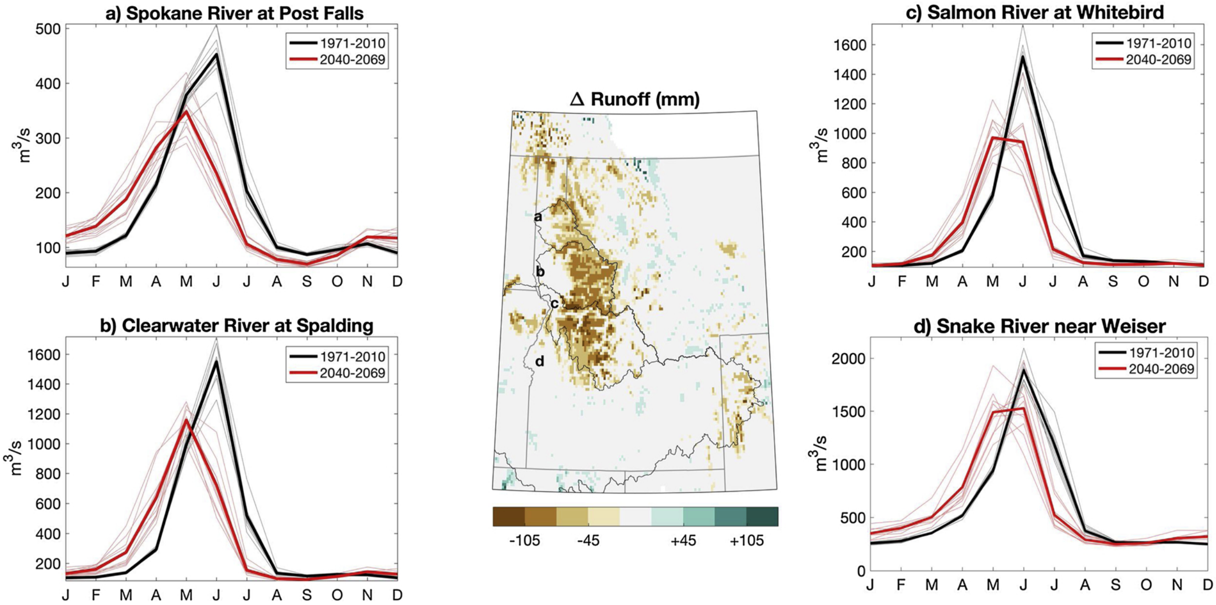

Fig. 3. Projected monthly average river discharge from 1971 to 2000 (black) to 2040–2069 (red) for four Idaho rivers: a) Spokane River at Post Falls; b) Clearwater River at Spalding; c) Salmon River at White Bird, and; d) Snake River at Hagerman. In each plot the bold line shows the 10-model average while the thin lines show results for individual models. (center) Projected change in 10-model mean annual surface runoff for Idaho averaged over the mid-21st century (2040–2069) versus for contemporary climate (1971–2000).

Hamlet et al., 2010; Xin and Sridhar, 2012; Vano et al., 2015). For example, 1 April volumetric snowpack storage derived from VIC across Idaho is projected to decrease by a third by the mid-21st century (Gergel et al., 2017).

Despite declines in spring snowpack, increased summer potential ET, earlier runoff and subsequent declines in summer streamflow, changes in annual volumetric runoff are rather small (Fig. 3, Table 2). Increased annual precipitation acts to buffer declines in streamflow (Table 2). The multi-model mean reduction in modeled streamflow by the mid-21st century is 0–13%, with the largest decreases in the Salmon River (-13%) and Clearwater River (-11%) and a nominal change in the Snake River (-0.5%). Notably, there is substantial intermodel variability with some models showing decreases exceeding 20% for some basins, while other models project increases exceeding 10% for some basins. Projected changes in annual runoff are consistent with results using a previous generation of models (e.g., Hamlet et al., 2010; Sridhar et al., 2013), and other empirical approaches (e.g., Abatzoglou and Ficklin, 2017). In contrast, volumetric runoff is projected to decrease across much of the southwestern United States with climate change, including reductions from 10 to 45% in the Colorado River Basin by the mid-21st century (Das et al., 2011; Vano et al., 2013). As a caveat, some modeling results suggest that declines in annual runoff are overestimated due to procedures used by offline hydrologic models and estimates for potential ET (Milly and Dunne, 2017).

In contrast to the subtle and more varied changes in volumetric runoff under climate scenarios, the timing of surface water runoff is projected to change substantially. While the magnitude of these changes vary by basin, they generally involve a 1–2 month advancement in the peak runoff month, with increased flow during the winter months and decreased flow in summer due to changes in mountain snowpack storage and melt (Fig. 3). The advancement in the timing of snowmelt and subsequent earlier drawdown of soil moisture results in decreased summer soil moisture (e.g., Gergel et al., 2017) and increased climatic water deficit (potential minus actual ET) that has ecological consequences and may increase water demand for irrigated agriculture.

3.1.2. Projections of extreme events and disturbance factors

In addition to changes in mean conditions, climate change may alter the frequency, timing, and magnitude of extreme events including those that affect water commodities and hazards associated with water supply. These include changes in flooding potential, rain-on-snow events, and drought duration and intensity (Hamlet and Lettenmaier, 2007; Musselman et al., 2018). Some drought measures suggest that the arid portions of Idaho will see increases in the frequency of severe drought conditions with climate change (e.g., Ficklin et al., 2016), although less severe than changes projected for the southwestern US (Gutzler and Robbins, 2011). Increases in the frequency and magnitude of heat extremes and summer drought are projected to lead to more frequent large wildfires across the northwestern United States (Barbero et al., 2015) that have implications for postfire water quality and yields.

3.2. Water consumption

3.2.1. Projections of population change

Idaho's population in 2017 was 1.71 million; by 2030 it is estimated to be 1.9 million, an increase of 52% (USCB (United States Census Bureau)., 2017). In Idaho, and particularly in southern Idaho where the majority of the population resides, a likely outcome of projected population increase is continued conversion of irrigated land to urban land, currently in the order of 5% per 5 years, and a concomitant decrease in water use. Projections for land use land cover change to urban land for the area encompassing southern Idaho and the Upper Snake River Basin from 2005 to 2050 estimate changes in land-use of less than 3% of the total area (Sleeter et al., 2012).

3.2.2. Projections of water consumption and supply deficits

Increased population across the western US will likely lead to increased domestic water needs. Although these increases are relatively small compared to irrigation usage, this will increase demand in the fully allocated water supply in places like the Upper Snake River Plain where settlements replace non-irrigated land. By contrast, the loss of irrigated cropland to urban development in the Upper Snake River Plain may offset water supply deficits by reducing water consumption. Additional uncertainty exists regarding the secondary water needs of the growing population in light of an increasingly globalized economy and unknown advances in technology and changes in policy, and similarly uncertainty in changes in croplands and their water demands (e.g., different cropping systems) in the next 50 years (Ryu et al., 2012).

Qualls et al. (2013) found that the current irrigation water storage and delivery infrastructure in Idaho is adequate to deal with future water shortages during dry years, yet is inadequate to capitalize on potential surpluses during wet years due to the lack of storage capacity. While the projection of earlier snowmelt and greater magnitude runoff peaks is consistent across the western US, Barnett et al. (2005) noted that current storage capacity in the western US is inadequate to handle the earlier runoff producing shortages in availability during peak demand periods. For Idaho, mid-21st century potential water surplus, defined as cumulative annual streamflow for watersheds contained within Idaho minus water use suggest relatively minor change for the 21st century, assuming unchanged water use, however taking into account projected population increase the mean potential water surplus can be expected to drop (Table 2). We note that these estimates consider potential water surplus, assuming that engineering solutions for countering changes in streamflow and surface water demands are incorporated. Finally, these projections do not consider the potential for changes in hydroclimatic extremes such as the occurrence of single or multi-year droughts that may tax water availability.

4. Implications for policy and water management

4.1. Water banking

Water banking will likely play an important role in meeting an increasing demand with a highly variable supply of water. Although the existing water banking programs in Idaho are fundamental to water use efficiency, maximizing the beneficial use of water, and maintaining equitable water distribution, delivering water to a greater diversity of users may require formal changes to the arrangements of Idaho's water institutions and their process for facilitating water banking and transfers. To meet growing demands for water within the state and across its boundaries with an uncertain future water supply, greater reliance on these institutions will be necessary to meet growing demands. Over the last five years, applications to the state water bank and the amount of water leased from the state water bank have increased (IDWR (Idaho Department of Water Resources), 2017). Projected reductions in summer water availability due to declines in spring snowpack and an advancement in the timing of snowmelt runoff will lead to more applicants seeking water (Cobourn et al., 2013). In order to meet the demand, the state recognizes that it needs to encourage greater participation from lessors. Within the Comprehensive State Water Plan, future goals for the Water Supply Bank include the need to "increase use,"…and provide more "efficient mechanisms that are responsive to both traditional and emerging needs for water".

While the current water banking system facilitates various water transactions, the state water plan recognizes that the banking system needs to evolve to improve efficiency of transactions. More efficient transactions and other evolving policy changes will help attract more water rights holders to lease water through the water banking system. In order to meet regional needs and changing societal values the concept of beneficial use and the efficiency of the water banking transaction must be allowed to continue. However great care will need to be taken that ensures that changes in policy do no harm to existing water users. The basic premise of *first-in-time, first-in-right,* which provides a guarantee and certainty to water resource distribution, must be protected so that all water distribution is as equitable as possible.

Inter-sectoral water transfers from agricultural use to others has been seen in others states including California, Arizona, Nevada, Colorado, Texas and New Mexico (Libecap, 2011). Policy makers should review the success and shortcomings of these transfers in light of existing Idaho water distribution practices. Perhaps it is possible through a reinterpretation of the beneficial use clause of the prior appropriation doctrine to allow water to be used for sectors other than agriculture, which will provide water users more of an incentive to sell their water temporarily to buyers in need, in turn enhancing the water banking and transfer system (Cobourn et al., 2013). Reinterpreting the beneficial use of water can facilitate changes in the use of water to include more emergent future water needs that can accommodate both in-state and out-of-state water use (Slaughter et al., 2010; IWRB, 2012).

4.2. Water rights adjudications

Aside from the presence of water institutions that facilitate water banking participation in the state (Slaughter 2005), another advantage of Idaho's current water appropriation system for increasing participation is its effort to formally adjudicate all waters within the state in recent decades (Tuthill, 2006). A formal adjudication of water rights allows for better accountability in terms of administering water rights, and provides the state with an inventory in terms of who owns water, the priority date, the beneficial use the water is put to, where the user's diversion is located within a basin, etc. (Slaughter et al., 2010; Harris, 2015), facilitating the ease and legitimacy of water transfers, leases, and sales. This process involves the determination of state courts as to what water rights exist within a basin, and is informed by the technical expertise of the Idaho Department of Water Resources (Rassier, 2016).

The institutional frameworks for water management in Idaho and the western U.S. externalize costs and have to contend with competing management objectives leading to a difficult balancing act among competitive markets, public regulation, and public allocation (Chong and Sunding, 2006; Slaughter et al., 2010). As regional needs for water resources continue to expand, population within Idaho grows, the climate changes, and water resources have to be stretched farther, the need to creatively adapt prior-appropriation and maintain the state's sovereignty over water resources will be key to the long term sustainability of Idaho's economy and environment.

5. The outlook for Idaho's waterscapes

Water management is inevitably dealt with from an allocation and policy approach rather than a systems approach (Wang et al., 2016). We advocate for the use of a science of integration, that considers the physical, biological, social and economic aspects within the same framework (Alessa et al., 2011; Kliskey et al., 2016). If we look at the basic supply context, Northern Idaho currently has and is projected to have an overall water surplus in the near future, on average. Southern Idaho will continue its trajectory toward water deficits that will likely become amplified based on: 1) reduced groundwater recharge; 2) reduced snowpack storage leading to altered timing of runoff, and; 3) current consumptive practices continuing. To achieve this we propose an explicit consideration of Idaho's water in a regional context, and the consideration of plausible future water scenarios.

5.1. The need to understand Idaho's water in a regional context

Idaho's water challenges occur in the context of the broader regional venue – Idaho's location at the southern headwaters of the Columbia River Basin is critical with respect to downstream states, and the projected water surpluses in northern Idaho over the next 50 years. Regardless of how Idaho might choose to respond, an adaptive, long-term water plan is necessary to support any response. Idaho's State Water plan must continue to be flexible and revised proactively if the state is to maintain its resilience, protect its industries, and proactively respond to issues regarding water shortages and water commodification across the western US. For example, inter-basin transfers of water might be considered as a solution to the projected declines in water availability in Southern Idaho relative to the projected abundance of water in Northern Idaho, requiring further development of the institutional mechanisms to support such transfers (Meyer and Pursley, 2010; Slaughter et al., 2010).

Further, there are social, economic and ecological reasons for keeping water in a watershed particularly when facing uncertain conditions. Diminishment of instream flows would likely have major consequences for transporting water out of a basin and this is detrimental to aquatic ecosystems. The idea of moving water out of basins is also contrary to the idea of managing along watershed boundaries. The watershed boundary as the basis for water management in the west is not new, having been proposed by John Wesley Powell in the 1870s through watershed communities, that is, a system of small farms organized into irrigation districts, and ranches organized into grazing districts, that share equally in the ownership of the water (Powell, 1879; Worster, 2003, 2009;). This is consistent with suggestions to re-emphasize water management as a place-based endeavor at local watershed scales (Palmer et al., 2009) and a combination of both water supply and water demand management strategies are required to address environmental uncertainties (Wang et al., 2016). These approaches support a strong body of water management practice on shared vision planning that includes multi-objective planning (Werick and Palmer, 2008; Palmer et al., 2013).

5.2. Consideration of future water scenarios

In considering the outlook for Idaho's waterscapes and future planning it is useful to consider what the state might look like in 50 years (Table 2). For argument's sake we consider two scenarios for possible responses. Scenarios are not predictions about the future, rather they are plausible alternatives of what might transpire under particular sets of assumptions and projections (Kepner et al., 2004).

A baseline scenario (Scenario A) reflects the status quo – a do nothing, business-as-usual response (Stewart et al., 2004) – where a static state water plan might have detrimental consequences for communities and industry in southern Idaho given the prospects of declining water availability during the summer months, and potential regional deficits within parts of the Snake River Plain. Projected hydroclimatic changes for Idaho in the next 50 years (Table 2, Fig. 3) – namely, warming temperatures, decreases in summer runoff, and increases in water consumption – place Idaho at risk of increased water deficits under this scenario. This risk could be reduced in some parts of the State through greater adoption of water banking and water market mechanisms, however, current water rights based on prior appropriation would potentially offset any gains (Chong and Sunding, 2006). Under Scenario A, Idaho, and particularly southern and central Idaho, face the risk of potential water deficits in the next 50 years, without careful intervention.

A conservative scenario (Scenario B) applies the same projected hydroclimatic changes, but introduces the implementation of a set of adaptive responses – these might include in-state water management and inter-basin transfers. Such a suite of responses might provide some relief to projected deficits in southern Idaho courtesy of water conservation measures, greater re-use of water between sectors, and some water transfers from the northern Idaho basins. Under Scenario B, reduced regional deficits and reduced net water consumption are possible in the next 50 years with strategic planning for a set of adaptive responses that consider the regional context of Idaho's hydroclimate and the social and institutional context of water management (Meinzen-Dick, 2007).

The consideration of these two scenarios, and potentially other alternative scenarios, highlight the potential choices available to Idaho and allow for consideration of the losses and gains that might accrue from particular decisions. This approach can provide added value to the established collaborative modeling practices for water resource planning or shared vision planning (Werick and Palmer, 2008; Palmer et al., 2013; Langsdale et al., 2013).

6. Conclusion

Understanding future water availability and use is critical for an expanding economy and population, and for sustainable ecosystems, in Idaho. This paper fills a gap in the understanding of how environmental and landscape changes will impact contributions to the regional water system, that is, Idaho's waterscapes. We have examined how Idaho's waterscapes have evolved and adapted historically, and how these waterscapes are likely to continue to evolve into the future in a regional context. We focus on addressing changes in the input side of waterscapes under projected changes through to 2050 in the context of existing and evolving water rights, institutions, and policy. In southern Idaho reduced water availability during times of peak demand is a robust result of projected changes in climate. Future water use will continue to be overwhelmingly dominated by agricultural demand. This implies that the greatest policy and management opportunities lie in this sector (Xu and Lowe, 2018). These include greater emphasis on water banking changes, reuse and storage. For example, water banking via local rental pools could be expanded from water rights for existing reservoirs to incentivize the development of more reservoir storage as a way to cope with water scarcity and declines in snowpack storage and consequently creating opportunities to increase storage. Policy supporting the management of water resources will require that Idaho's institutions and governance continue to adapt and be flexible under change (Moore and Willey, 1991; Slaughter and Wiener, 2007; Cosens and Williams, 2012). Consideration of adaptive policies and planning approaches based on an understanding of the interconnected physical and social aspects of water, i.e., waterscapes, and the potential impacts on waterscapes under plausible future scenarios, offers some valuable proactive directions for a more secure water future in Idaho and other parts of the US.

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