Keeping Wetlands Wet in the Western United States: Adaptations to Drought in Agriculture-Dominated Human Natural Systems

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Keeping wetlands wet in the western United States: Adaptations to drought in agriculture-dominated human-natural systems

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A B S T R A C T

Water is critical to protecting wetlands in arid regions, especially in agriculture-dominated watersheds. This comparative case study analyzes three federal wildlife refuges in the Bear River Basin of the U.S. West where refuge managers secured water supplies by adapting to their local environmental context and their refuge's relationship to agriculture in being either irrigation-dependent, reservoir-adjacent or diked-delta wetlands. We found that each refuge's position confers different opportunities for securing a water supply and entails unique management challenges linked to agricultural water uses. Acquiring contextually-appropriate water rights portfolios was important for protecting these arid region wetlands and was accomplished through various strategies. Once acquired, water is managed to buffer wetlands against fluctuations caused by a dynamic climate and agricultural demands, especially during droughts. Management plans are responsive to needs of neighboring water users and values of the public at large. Such context-specific adaptations will be critical as the West faces climate change and population growth that threaten wetlands and agricultural systems to which they are linked.

1. Introduction

1.1. Water supplies are critical for wetland health and function

Water is the driving force in wetlands, responsible for their structure and function (Faulkner et al., 2011; Keddy et al., 2009). Water also links wetland managers to other water users across ownership boundaries in coupled human-natural systems (Falkenmark, 2004; Liu et al., 2007a). These linkages are evident in the ways hydrologic manipulation through impoundment and diversion of rivers has destroyed wetlands in some places and created wetlands in other locations. Early wetland policies in the U.S. encouraged wetland destruction in favor of other land uses, but more recently policies like the Clean Water Act have been established to protect wetlands (Eckles, 2011; Vileisis, 1997). Conservation policies have successfully slowed wetland loss; however, the focus of these policies has been to protect land designated as wetlands rather than the water supplies crucial to wetland function (Brinson and Eckles, 2011; Iza, 2004; MacDonnell, 1991).

In the West, water is scarce, highly contested, and heavily managed while wetlands are rare and ecologically valuable (Barnett et al., 2008; Dahl, 2011). As rivers in this region were allocated and diverted for human use, the timing and distribution of flooding changed, as did wetland distribution, which generally decreased (Langston, 2003; Reisner, 1989). Wildlife refuges were established to protect remaining wetland habitat and managers made additional changes as they began manipulating water within refuge boundaries to actively manage for wildlife (Downard, 2010; Welsh et al., 2013). Periodic drought is a natural part of wetland hydrology; however, extended drought or increased hydrologic variability, which climate change models suggest will increase, can severely impair ecosystem functions (Burkett and Kusler, 2000; Zedler, 2009).

1.2. Managing wetlands in the context of agriculture and western water law

The geographic and socio-political position of wetlands in relation to other water uses determines the frequency and magnitude of drought in wetlands and presents varying opportunities for securing and managing water. Wetland water

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management in agriculture-dominated watersheds requires recognizing and adapting to 1) hydrologic connections between water users, where one user's return flow may be another's water source; 2) shifting wetland distribution away from deltas and toward reservoirs and canals; and, 3) human linkages built at various scales as users adapt water allocation institutions to drought and changing uses of water.

Under the prior appropriation system dominant in the West, water rights are allocated by states on a "first in time, first in right" basis. Water shortages are not shared during droughts; thus, water users with older, "senior" water rights have greater security and experience drought differently than those with "junior" water rights (Getches, 2009). Environmental uses of water (including wetlands) were not legally recognized by most states until the 1970s, resulting in appropriations for these uses generally having junior priorities or "paper water" rights without actual practical access to "wet water" (Hillman et al., 2012). However, there are other means to secure a water supply, outside of applying for state water rights, and the security of a water supply does not necessarily depend upon the seniority of a water right (Baron et al., 2002; Grey and Sadoff, 2007). During times of drought, cooperation between neighboring land owners, outside the formal requirements of water law, can alleviate negative impacts of water scarcity (Endter-Wada et al., 2009).

In agricultural-dominated human-natural systems, wetlands can be characterized in terms of three relationships they commonly have to their water supply: diked-delta, reservoir-adjacent, and irrigation dependent. Diking wetlands to buffer against drought or extreme hydrologic fluctuations is a common management adaptation to upstream hydrologic change, particularly in deltaic wetlands in lower reaches of rivers (Haig et al., 1998; Zedler and Kercher, 2005). The regulation of western rivers was facilitated by construction of reservoirs for water storage, hydropower production, and flood regulation, which created wetlands near these new, more permanent water sources (Doll et al., 2009; Volz, 1995). Wetlands created by and dependent on flood irrigation, agricultural return flows, and canal seepage are especially ecologically valuable because they often exist in regions where natural wetlands are rare and/or impaired (Copeland et al., 2010; Peck and Lovvorn, 2001).

1.3. Significance of this comparative case study of wetlands in the Bear River Basin

The Bear River Basin is characteristic of most river basins in arid regions: heavily-managed, dominated by agriculture, and structured by histories of human adaptations to droughts (Endter-Wada et al., 2009). However, the Basin is unique in having many large wetland complexes that provide critical migratory bird habitat (Aldrich and Paul, 2002; Tiner, 2003). In this comparative case study of Bear River Basin wetlands, we examine how the locations of three U.S. Fish and Wildlife Service (USFWS) refuges impacts the way they experience droughts and the water management adaptations managers have made. While being managed by the same agency and located within the same watershed, the contextualized position at each refuge in relation to available stream flow, adjacent land uses, and water rights seniorities has led managers to pursue different means of securing wetland water supplies. Understanding how wetland managers have adapted to drought in the U.S. West requires qualitative, multi-method research of context at multiple scales with a focus on historical trajectories, hydrologic realities, and local institutions and legislation. Lessons learned by refuge managers in adapting to the challenges and opportunities of their location along the river can be applied in other arid, agriculture-dominated watersheds.

2. Context – the Bear River Basin

2.1. Hydrology of a dynamic, agriculture-dominated river

The Bear River runs for 800 km through the states of Utah, Wyoming and Idaho (Fig. 1) in a semi-arid climate that only receives 54 cm of annual precipitation. Stream flow is driven by snowpack that accumulates in the mountains and is stored in reservoirs during spring runoff for release during the irrigation season. Annual stream flow is naturally highly variable and difficult to predict, and the Bear River is usually experiencing either drought or flooding. Since European settlement, the river's natural hydrology has been altered by reservoirs, canals and other infrastructure needed to support agriculture and hydropower operations. Regional climate models predict higher rates of evapotranspiration, more frequent and severe droughts and floods, and a shift in precipitation from snow to rain, creating challenges for a water management system engineered to capture snowmelt (Lundquist et al., 2009; Mote, 2009).

2.2. Policy adaptations to unpredictable, drought-prone hydrology

Historically, severe droughts have led to important policy developments in order to decrease conflict between water users. Senior rights to the Bear River under the rules of prior appropriation were first claimed in 1862. The basic tenants of prior appropriation were subsequently modified by other policies that together form the Law of the Bear River, the most prominent of which is the Bear River Compact that divides the river into three divisions (Upper, Central, and Lower), allocates storage rights and delivery obligations between the divisions, and establishes protocols for drought mitigation (Jibson, 1991). Other additions to the Law of the Bear River include court decrees and adjudications, state constitutions and water development plans, and reservoir operation agreements. Agriculture is the primary use of Bear River water, but PacifiCorp, a power company, is responsible for management of six large reservoirs on the river and is influential in river management decisions. Despite a long history of water development, the Bear River remains one of the few basins open to new appropriations in the West (UDWRe, 2004).

2.3. Shifting wetland distribution in response to hydrologic changes

The impoundment, diversion, and delivery of Bear River water has changed the spatial and temporal availability of water and led to shifts in wetland distribution from lower reaches of the river to areas upstream. Migratory birds followed this shifting distribution of wetlands, providing the rationale for refuge designations. The Bear River terminates in a delta with the Great Salt Lake (GSL), a hyper-saline, terminal lake located in Utah. Water that flows into GSL is considered wasted under western water law, and little water reaches the lake during the irrigation season, extensively dewatering the delta; however, millions of migratory birds on the Central and Pacific flyways utilize these wetlands (Ivey and Herziger, 2006). Bear River Migratory Bird Refuge was established to protect the remaining delta from further degradation. The same diversions that dewatered the delta expanded a smaller complex of wetlands in Idaho associated with Bear Lake when the lake was augmented to act as a storage reservoir, and these expanded wetlands became the Bear Lake National Wildlife Refuge. Application of diverted Bear River water in the upstream mountain valleys of Wyoming created large wetland complexes amongst vast expanses of rangeland, as is the case with Cokeville Meadows National Wildlife Refuge.

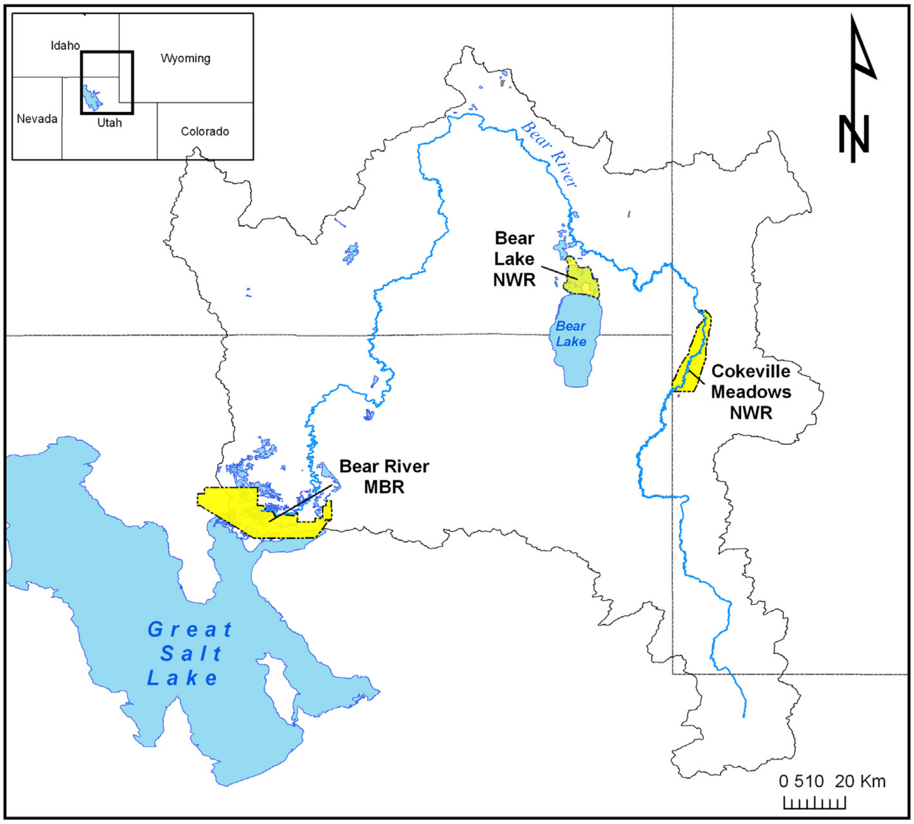

Fig. 1. U.S. Fish and Wildlife Service Refuges within the Bear River Basin of Utah, Idaho, and Wyoming.

3. Methods

For this policy and law-based comparative case study, data were gathered from multiple sources, including semi-structured key informant interviews, water rights records, and historical documents. *Key informant interviews* were conducted in 2009–2010 with current and retired wetland managers, regional water rights experts, members of conservation groups and wetland research agencies. Initial key informant interviewees were identified and then additional interviewees were selected through reputational and snowball sampling. Interviews were conducted under a protocol approved by Utah State University's Institutional Review Board, listed in Table 1, and were recorded, transcribed, and analyzed for themes and insights in wetland water management (Gubrium and Holstein, 2002).

Table 1
Questions used to guide semi-structured key-informant interviews conducted in 2009 and 2010.

1. Where does the water come from that maintains ("Bear River" or specific reference) wetlands?
   Probes: Do (these) wetlands have certificated water rights? If so, what is the nature of those rights? If not, how is the water secured?
2. How much water, in terms of amount and frequency, do these wetlands need?
3. What happens to ("Bear River" or specific reference) wetlands in times of drought?
4. Is maintenance of ("Bear River" or "these") wetlands controversial? Can you explain?
   Probes: What groups or individuals are involved in this controversy?
5. What are the constraints to obtaining enough water to maintain these wetlands?
   Probes: What constraints operate on an annual basis? What constraints pertain in times of scarcity?
6. What are the opportunities for obtaining enough water to maintain these wetlands?
   Probes: What is the role of formal water rights applications? What is the role of informal agreements?
7. How do natural resource agencies take wetlands into account in their planning processes?
8. How does your state division of water rights take wetlands into account when reviewing water use applications (e.g. applications for new appropriations or changes of use)?
9. I would be interested in hearing your opinions about wetland policies.
   Probes: What do you think are the strengths and weaknesses of those policies?
10. Do the policies and politics differ depending upon the geographic location of the wetland involved? Can you explain?

A multi-method approach (Neuman, 2009) was used to assemble *water right portfolios* for each refuge. Initial searches of state online water rights databases were conducted on owner names and place of water use and verified and supplemented by information from key informant interviews. Interviews that was critical for identifying newly acquired water rights not yet reflected in state databases, and for identifying access to water through shares held in irrigation companies. Stream gage data gathered from the U.S. Geological Survey (USGS) identified the reliability of formal water rights to provide practical access to water.

Legal and historical documents were used to identify developments in drought adaptation strategies, while management documents were used to understand current management approaches, concerns, and adaptations. Legal documentation included water management agreements, pertinent sections of state constitutions, relevant state and federal legislation, and wildlife and water agency policies. Historical documents included local histories, irrigation maps and ecological descriptions. Acquisition of secondary documentation was facilitated and validated by interviewees, who helped researchers appropriately understand and contextualize the water rights portfolios.

4. Results – comparative case studies of wetland water management

4.1. Case study #1 – irrigation-dependent wetlands – conserving wildlife habitat created by irrigation at Cokeville Meadows NWR

Cokeville Meadows National Wildlife Refuge (NWR), located in the Bear River Valley of southwestern Wyoming (Fig. 2), is the smallest and youngest addition to the Refuge System in the Bear River Basin, established in 1993 and incorporating 3747 hectares (ha) (USFWS, 2012a). Interviews and historical imagery indicate the original riparian wetlands associated with the Bear River and its tributaries were significantly enhanced as development of flood irrigation created more than 10,927 ha of seasonally-flooded emergent wetlands (Utah State Planning Board, 1939). These irrigation-dependent wetlands represent rare and productive waterfowl habitat in Wyoming, which led biologists to suggest the area be protected as a wildlife refuge (USFWS, 1992). Following the establishment of Cokeville Meadows NWR, the USFWS began acquiring land and accompanying water rights from voluntary sellers within a 7284-ha acquisition boundary.

4.1.1. Predictability of water delivery in an agricultural valley high in the watershed

Several infrastructure components link Cokeville Meadows NWR wetlands to agricultural water delivery, including a dam,

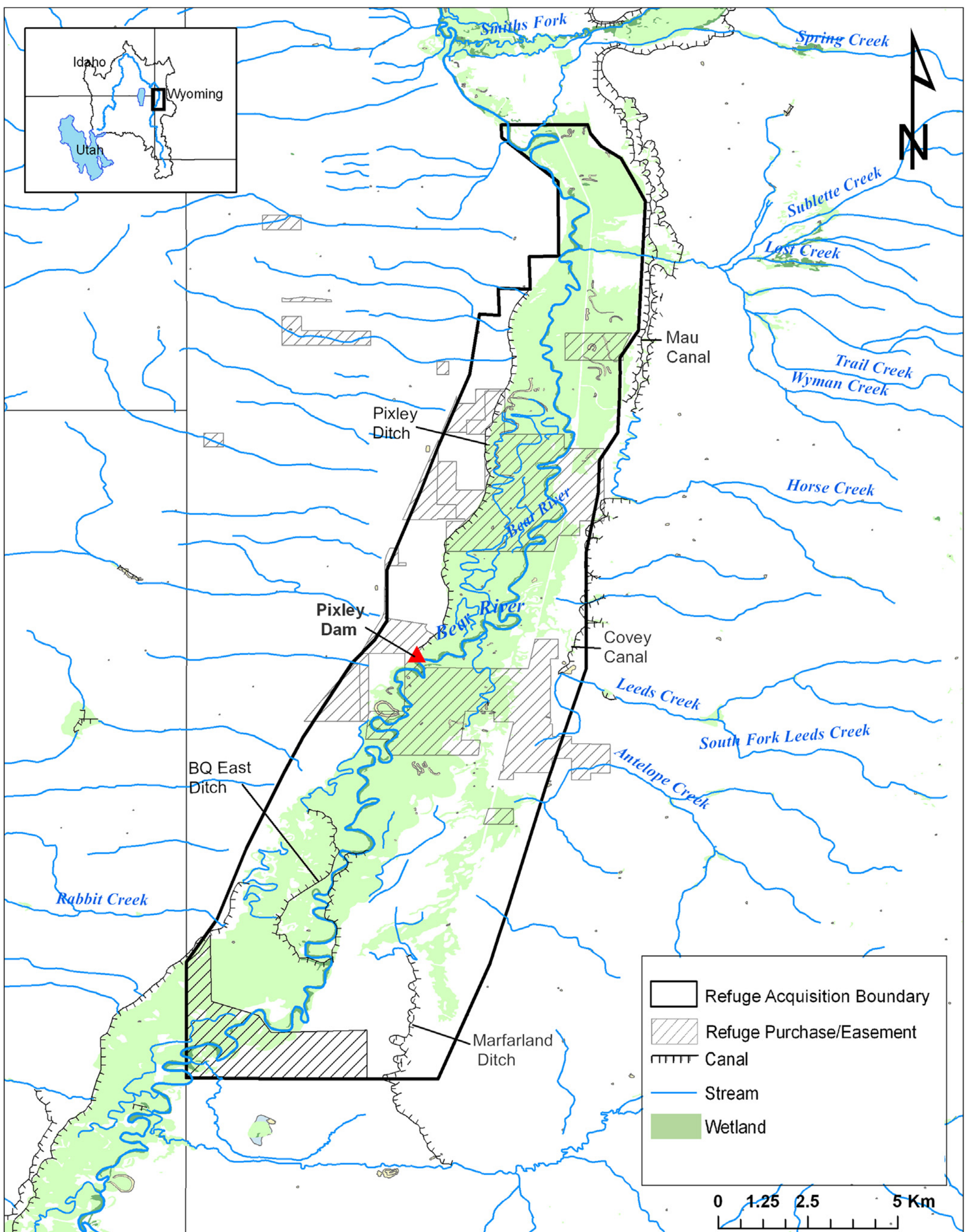

Fig. 2. Cokeville Meadows National Wildlife Refuge, Wyoming.

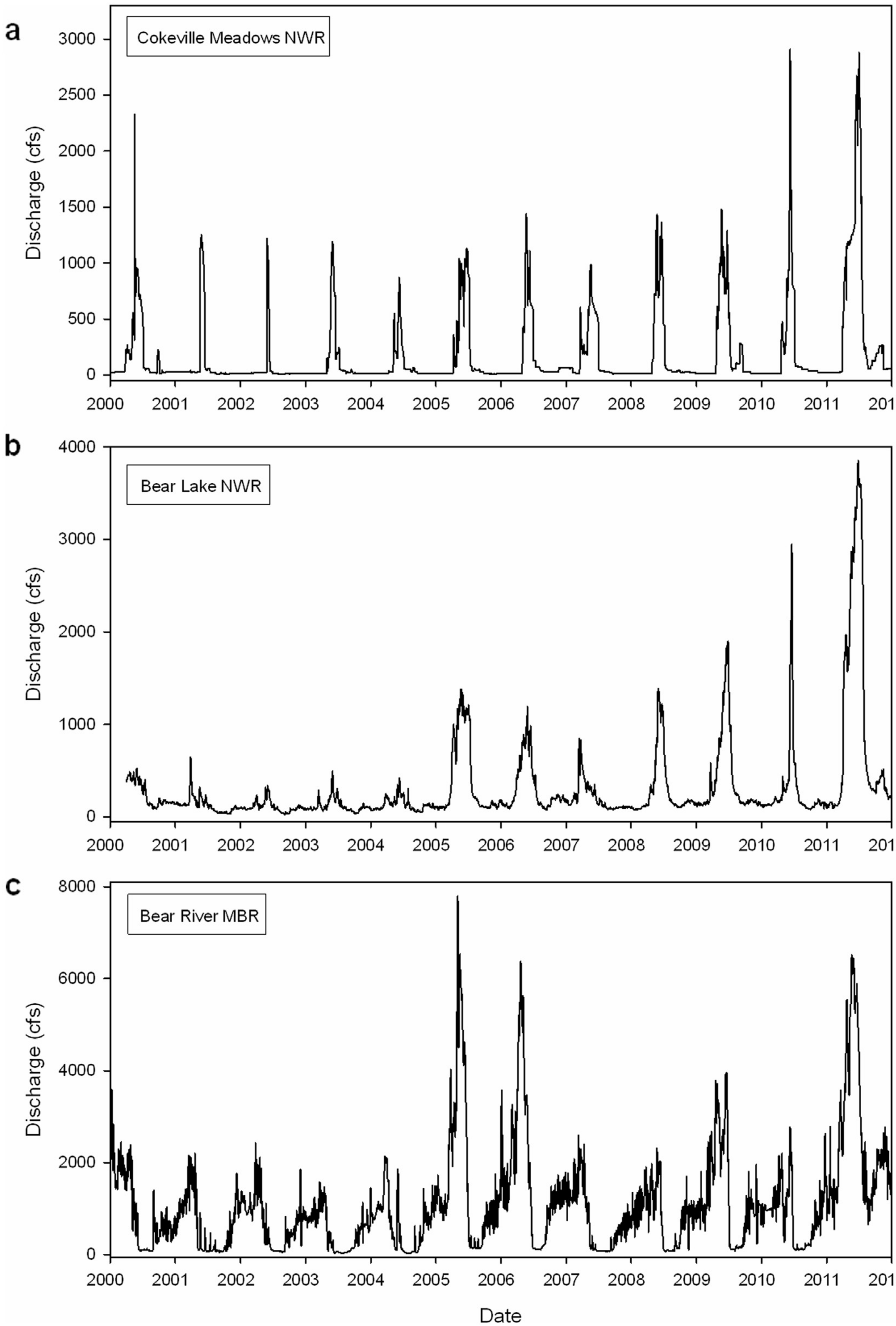

Fig. 3. Discharge of the Bear River from January 2000 to December 2011 above three Bear River Basin wildlife refuges: a) at Cokeville Meadows NWR (USGS gage 10020300 below Woodruff Narrows Reservoir); b) at Bear Lake NWR (USGS gage 10039500 at Border); and, c) at Bear River MBR (USGS gage 1013600 at Corinne). Note differences in scale on the *y*-axis.

several canals, and multiple groundwater pumps. Stream flow in the Bear River upstream of Cokeville Meadows NWR follows a characteristic snowpack-driven pattern, peaking in June and decreasing over the summer until the driest part of the year in September, though stream flow does vary significantly between years (Fig. 3). The overall mean monthly discharge in dry months can be as little as 1% of discharge in wet months, and wet years are significantly more hydrologically dynamic than drought years

Table 2
Canal company shares and water rights held by USFWS for use at Cokeville Meadows NWR (3747 ha, established 1993); (Wyoming State Engineer's Office, 2012).

Priority date	Flow rate[a]	Water source	Designated beneficial use[b]
Canal shares			
1878	-[c]	BQ Dam East Ditch – Bear River	Irrigation
1880	–	Pixley Irrigating Ditch West – Bear River	Irrigation
1881	–	Pixley Irrigation Ditch – Bear River	Irrigation
1881	–	North Lake Ditch – North Lake Spring Creek	Irrigation
1888	–	Leeds Creek Ditch – Leeds Creek	Irrigation
1897	–	Mau Canal Enlargement – Smith's Fork	Irrigation, Domestic
1901	–	Macfarland Ditch – Bear River	Irrigation
1907	–	Pixley Ditch Enlargement – Bear River	Irrigation
1908	–	Succor Spring Ditch – Succor Spring	Irrigation, Stock, Domestic
1909	–	Covey Canal – Smith's Fork	Irrigation, Domestic
1925	–	Tanner Supply Ditch – Antelope Creek	Irrigation
Groundwater claims			
1959	900 gpm	Groundwater – Etcheverry Well#1	Irrigation
1959	1900 gpm	Groundwater – Thornock Bros#1	Irrigation
1972	25 gpm	Groundwater – Cornia Well#1	Stock, Miscellaneous, Domestic
1972	25 gpm	Groundwater – Cornia Well#2	Domestic, Stock
1977	1300 gpm	Groundwater – Cornia Well#3	Stock, Irrigation
1977	1140 gpm	Groundwater – Bartek#1 Well	Irrigation
1981	1200 gpm	Groundwater – Thornock Well#3	Irrigation, Stock
1982	200 gpm	Groundwater – Thornock Well#3 Enlargement	Irrigation
1982	25 gpm	Groundwater – Buckley Well#3	Domestic, Stock
1982	1000 gpm	Groundwater – Buckley Well#4 Enlargement	Irrigation
1984	450 gpm	Groundwater – Buckley Well#4 Enlargement	Irrigation
1993	400 gpm	Groundwater – Beckwith#1	Irrigation
1998	0 gpm	Groundwater – Beckwith#1 Enlargement	Irrigation
Storage rights			
1879	2.30 cfs	Pixley Dam – Bear River	Irrigation
1914	1.22 cfs	Ellen Reservoir – Antelope Creek	Irrigation

[a] gpm = gallons per minute, where 448.8 gpm is equivalent to 1 cfs; cfs = cubic feet per second, which is equivalent to 1.98 acre feet per day.
[b] Irrigation rights can be diverted only during the growing season (April–October). Domestic rights can be used all year long. Stock rights can be used all year long to provide water for animals, but all stock rights represent a small portion of overall rights.
[c] Quantity of water associated with canal company shares and storage rights are not listed because distribution is dependent upon annual water supply and number of shares held.

(USGS, 2012a). Variation in Bear River stream flow near Cokeville Meadows NWR is buffered by the refuge's diverse portfolio of water rights.

4.1.2. Utilizing historical water rights and irrigation infrastructure and practices for wetland management

The USFWS has acquired shares in multiple canal companies and groundwater and storage rights with irrigated lands purchased for the refuge. Shares in 11 irrigation companies represent the bulk of the refuge's water supply; these companies have senior water rights to divert surface flows from the Bear River and smaller tributaries. Irrigation canals are generally full during the irrigation season when natural stream flow is low, thus ensuring a reliable water supply for the refuge during periods of drought. Surface water rights are supplemented by 13 groundwater rights, and storage rights in two local reservoirs (Table 2).

The water rights portfolio held by Cokeville Meadows NWR is made even more secure by conditions of the Bear River Compact, which specifies water deliveries the Upper Division of the watershed must make to the Central Division. The boundary between these two divisions is located at the center of Cokeville Meadows NWR (Public Law 96-189, 1980). This compact provision ensures that no major changes to the river will occur upstream of the refuge because of downstream delivery obligations, as long as the interstate compact is in effect. Altogether, refuge managers assess their water supply availability as being adequate to meet wetland needs.

According to refuge managers, water management is the primary job at Cokeville Meadows NWR; however, the refuge lacks an explicit wildlife-based water management plan, which is critical to utilizing water to effectively manage wetland habitat. Current water management is focused on developing an understanding of the refuge's water rights, maintaining infrastructure, irrigating meadow hay, and coordinating with the needs of neighboring agricultural water users. Cokeville Meadows NWR is a wetland complex within a larger landscape of mixed private and public land and water rights ownership. Managing water in this setting requires communication between refuge managers, nearby landowners and state agencies to distribute water among users through shared infrastructure. This extensive communication will prove advantageous as the refuge prepares to open to the public in coming years. The predicted climate change-driven shift from snow to rain in the region could threaten the security of this refuge's water supply that is predicated on capturing snowmelt. Future management will depend upon adapting to new regional climatic and hydrologic patterns.

4.1.3. Adapting wetland management in cooperation with agricultural neighbors

Interviewees identified three ways people involved in establishing and securing a water supply for Cokeville Meadows NWR have adapted wetland management to this irrigation-dependent context. The first adaptation was recognizing the habitat value of irrigation-dependent wetlands and seeking their protection through designation as a wildlife refuge. Second, managers acquired senior irrigation water rights and infrastructure as part of land purchased for the refuge. Lastly, refuge managers have nurtured human linkages within the community of water users that are crucial for adaptation.

Acquisition of water rights for Cokeville Meadows NWR was made possible by managers building good working relationships with the Wyoming State Engineer's Office and the Game and Fish Department during refuge establishment. Communication helped ease uncertainty among valley residents about the federal government intruding into rural life, kept refuge managers informed of relevant water-related decisions, and increased refuge managers' capacity to adapt to drought. These temporary adaptations will likely be built into long-term (15-year) management plans during the Comprehensive Conservation Planning (CCP) process, which requires public participation and will include a plan for managing water on refuge lands that recognizes opportunities available to irrigation-dependent wetlands (U.S. Code, 1997). Refuge managers are currently drafting their CCP. Communication and continued local adaptation will prove crucial for water management in irrigation-dependent wetlands as they adapt to future droughts predicted to be exacerbated by climate change.

4.2. Case study#2 – reservoir-adjacent wetlands – managing wetlands within the confines of water storage delivery operations at Bear Lake NWR

Bear Lake National Wildlife Refuge (NWR) is located in southeastern Idaho adjacent to the northern boundary of Bear Lake (Fig. 4), where 7353 ha of wetland habitat were set aside in 1968 to assist in the recovery of Canada goose populations (USFWS, 2012b). This region of the Bear River Basin has been extensively engineered to permanently connect Bear Lake to the Bear River, allowing the top 6.60 m of the lake to be used as a storage reservoir (Jibson, 1991). In 1918, PacifiCorp built two large canals through the original marsh: the Rainbow Canal diverts the Bear River south from

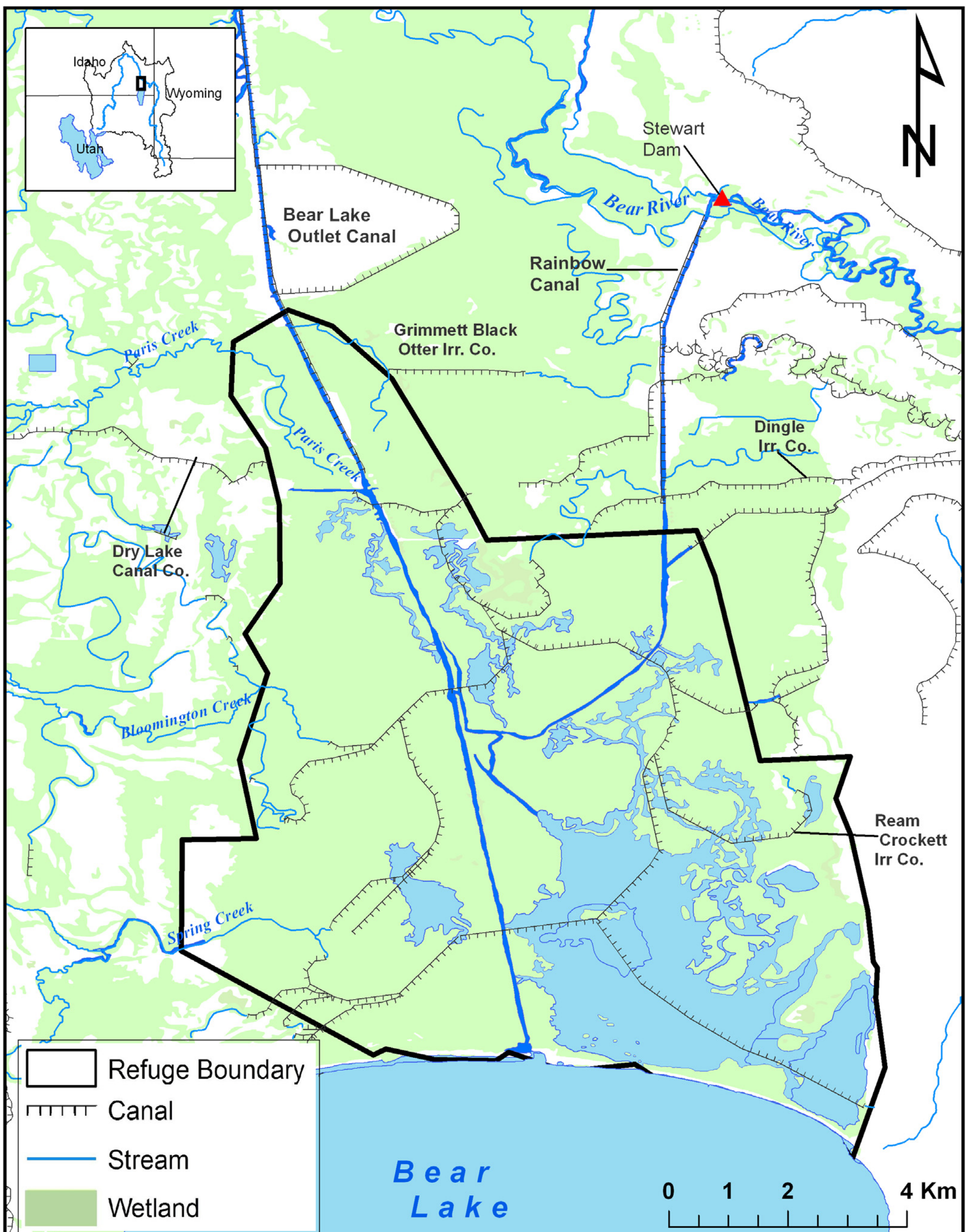

Fig. 4. Bear Lake National Wildlife Refuge, Idaho.

Stewart Dam into Bear Lake and the Bear Lake Outlet Canal takes storage water from the lake north back to the river channel (McCarthy, 1987). This major river management strategy has sustained a large complex of emergent and open water wetlands that provide habitat for waterfowl and colonial nesting birds.

4.2.1. Reliability of water supplies associated with reservoir operations and water delivery obligations

In addition to the canals PacifiCorp operates to manage storage in Bear Lake, several irrigation canals and Bear River tributaries drain into Bear Lake NWR. The refuge's geographic juxtaposition to these water sources creates a reliable, but variable, water supply for wetlands. The Bear River upstream of Bear Lake NWR displays a similar, snow-pack driven hydrograph as Cokeville Meadows NWR, but experiences less extreme annual fluctuations between high and low flow periods within a year, and greater inter-annual differences between drought and flood years (Fig. 3). At this section of the river, discharge during the dry season is usually 10% of the spring runoff flow (USGS, 2012b). Much like Cokeville Meadows NWR, low flow periods in the river near Bear Lake NWR are offset by canals, which contain water during the irrigation season. While reliable, these water sources fluctuate according to agricultural water delivery needs, so managers have addressed this management challenge by negotiating access to water from irrigation canals to improve refuge habitat.

4.2.2. Securing a wetland water supply through agreements with irrigation and hydropower operators

The USFWS actually holds no water rights for Bear Lake NWR, but they do own shares in four canal companies which hold senior water rights (Table 3). More importantly, refuge managers worked out an agreement with PacifiCorp to draw the water level in the Rainbow Canal up or down by 15 cm and divert that water into wetlands in order to meet wildlife needs. The storage rights PacifiCorp holds for the Rainbow Canal are very reliable because the canal diverts water for irrigators in the Lower Division of Bear River who have the most senior water rights on the entire interstate river. Further, PacifiCorp agreed to keep the elevation of Bear Lake from dropping below levels that initiate a water emergency, ensuring that water will always be diverted into the lake (PacifiCorp, 2002; UDWRe, 2005).

Table 3
Water rights held by canal companies in which USFWS owns shares or has negotiated access to water for Bear River NWR (7353 ha, established 1968); (Idaho Department of Water Resources, 2012).

Priority date	Water source	Designated beneficial use[a]
Canal shares[b]		
1865	Dry Lake Canal Co. – Paris Creek	Irrigation
1877	Grimmett Black Otter Irr. Co. – Bear River	Irrigation, Stockwater, Wildlife
1877	Ream Crockett Irr. Co – Bear River	Irrigation, Stockwater
1884	Dingle Irrigation Co – Bear River	Irrigation
1884	Ream Crockett Irr. Co – Bear River	Irrigation
1885	Ream Crockett Irr. Co – Bear River	Irrigation
1890	PacifiCorp – Bloomington Creek	Irrigation
1894	PacifiCorp – St. Charles Creek	Irrigation
1898	Hemmert Hot Springs	Stockwater, Domestic, Recreation
1902	PacifiCorp – Bloomington Creek	Unspecified
1905	Dry Lake Canal Co. – Paris Creek	Irrigation
1969	Dingle Irrigation Co – Bear River	Irrigation
Storage rights		
1911	PacifiCorp – Bear River (Rainbow Canal)	Irrigation, Power from Storage
1912	PacifiCorp – Bear River (Rainbow Canal)	Irrigation, Power from Storage
1912	PacifiCorp – Bear River (Mud Lake)	Power from Storage

[a] Irrigation rights for canal companies can be diverted only during the growing season (April–October); PacifiCorp's irrigation rights may be used all year. Domestic and recreation rights can be used all year long. Stockwater rights can be used all year long, but all stockwater rights represent a small portion of overall rights. Power production from storage rights is limited to April–September to align its use with irrigation delivery needs.
[b] The quantity of canal and storage rights are not noted because distribution of rights is dependent upon annual supply and number of shares held.

Agreements for water use made with canal managers are complimented by the construction of dikes and canals within the refuge to deliver water where it is needed to maintain habitat and to prevent large, damaging fluctuations in water levels (USFWS, 2008). Through careful planning and water management, Bear Lake NWR managers create several types of wetlands with different water regimes. But, as is the case with Cokeville Meadows NWR, climate changes that would alter the snow-dominated precipitation that Bear Lake is designed to store could eventually threaten the nature of existing operations designed to use the lake as a reservoir.

4.2.3. Managing wetlands in sync with irrigation demands and reservoir operations

Interviewees identified two major adaptations Bear Lake NWR managers have made to take advantage of the refuge's location in relation to Bear Lake. The first adaptation was identifying wetland water sources and negotiating access to them. Doing so required extensive understanding of the engineered and political context of the region, especially the way the Law of the Bear River is built around reservoir operations at Bear Lake. Because of the importance of Bear Lake to the linked irrigation-delivery, power-production system of the Bear River, and the work refuge managers have done to build partnerships for their water management plans and infrastructure, Bear Lake NWR has a very reliable water supply.

The second adaptation to context at Bear Lake NWR is managing water to buffer the wetlands against fluctuations in water supply caused by irrigation demands and to maintain multiple types of wetlands. Current refuge managers are aware of the importance of actively managing water, so they continue to build diversions and impoundments to create more diverse habitat and to participate in local water user meetings. Bear Lake NWR managers recognize the need for communication with other people as they utilize their water shares in canal companies and discuss snowpack and irrigation demand forecasts. Adapting to climate change will require extensive work with the diverse set of water users interested in utilizing and preserving the lake. Bear Lake NWR is in the final stages of developing a CCP, which requires integrating climate change projections into long-term management plans (USFWS, 2012b). Because of their political and geographic location, the reservoir-adjacent wetlands of Bear Lake NWR may be better positioned to deal with future threats to their water supply than other refuges in the region.

4.3. Case study 3 – diked-delta wetlands – preventing wetland loss at the end of a heavily allocated river at Bear River Migratory Bird Refuge

Bear River Migratory Bird Refuge (MBR) was established in 1928 and encompasses 29,947 ha of freshwater and brackish open water, emergent and playa wetlands at the Bear River's delta with the GSL (Fig. 5). Impoundment, diversion, and delivery of Bear River water for irrigation and hydropower that sustains wetlands at Cokeville Meadows NWR and Bear Lake NWR has also led to serious water fluctuations in the delta, drying and reducing these extensive

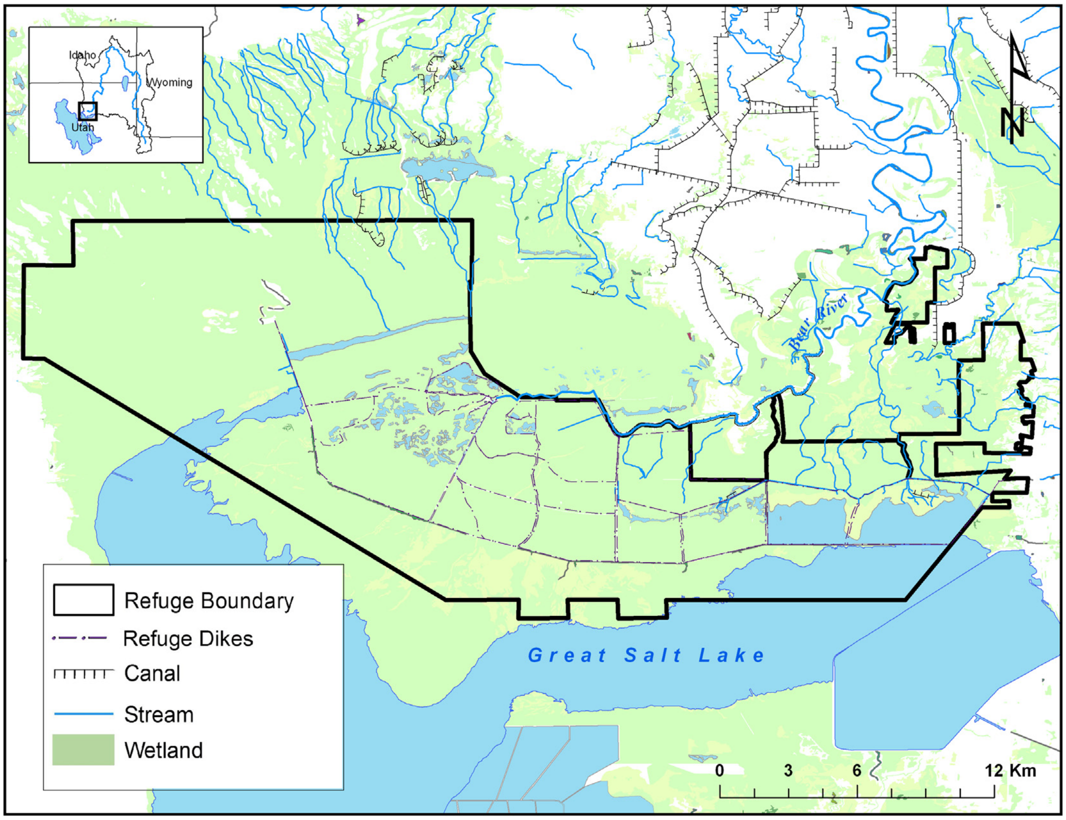

Fig. 5. Bear River Migratory Bird Refuge, Utah.

wetlands in low flow years or inundating them in flood years. In the past, irrigation season water shortages exacerbated outbreaks of avian botulism, which led area residents to petition Congress to establish a refuge at the delta (Wilson and Carson, 1950). The mission of the refuge was to create suitable habitat for migratory birds. In order to do this, managers immediately applied for water rights and constructed a system of dikes and canals to control water within the refuge to maintain these wetlands that support more than 260 bird species (USFWS, 1997).

4.3.1. Unreliable growing season stream flow in diked-delta wetlands

Bear River MBR is located downstream of all major diversions on the Bear River and has an unpredictable, extremely variable water supply. Stream discharge upstream of Bear River MBR can change by two degrees of magnitude over the course of the year, so drought-like conditions are a nearly-annual occurrence (Fig. 3; USGS, 2012c). Further, few other water sources are available for the refuge during the growing season and the refuge is associated with the GSL, which has no water right protections. Drought year hydrology displays great variability with long periods of low water, but flooding also represents a serious threat as there is no way to protect the refuge from rising hyper-saline waters of the GSL that have occasionally destroyed refuge buildings (Denton, 2007). Such unpredictable hydrology creates difficult wetland management challenges that Bear River MBR managers have worked to address through a combination of political adaptations, planning, and infrastructure development.

4.3.2. Acquiring access to limited water supplies and engaging in intensive water management

Water rights that are stored in Bear Lake are used just upstream of Bear River MBR, leaving little water in the river during most irrigation seasons, and fewer opportunities for securing access to sufficient water for such a large refuge. Managers have acquired a large portfolio of water rights that includes a primary, 1000 cubic feet per second (cfs) right to the Bear River with a 1928 priority date, as well as smaller senior rights to other water sources (Table 4). Acquiring this portfolio is a long-term effort involving applications for new rights, filing diligence claims, participating in court adjudications, and actively protesting new water rights in administrative hearings. Still, these efforts have resulted in more "paper water" rights (29 in total) than actual "wet water," especially during the irrigation season when water is critical for maintaining habitat. During most years, discharge in the Bear River drops well below 100 cfs during the summer months, creating drought-like conditions at Bear River MBR.

To address the challenge of maintaining wetland habitat without water during the irrigation season, managers at Bear River MBR pioneered a system of dikes and canals to divert and impound water within wetlands, an approach subsequently employed at other wetlands. This system allows managers to fill wetlands when water is plentiful in the early spring and draw them down slowly over the course of the summer, buffering the refuge from water shortages as much as possible. The water management infrastructure at Bear River MBR is complex, with 26 units and more than 90 miles of dikes, and managers have developed both annual and long-term water management plans based on calculated wetland water needs to effectively utilize this system (Downard et al., in revision). This strategy does not seek to mimic the natural hydrology of the Bear River, for which there is no historical record, but it represents an important strategy in maintaining wildlife habitat within an agriculture-dominated context (Kadlec and Adair, 1994).

A key part of planning is building on annual snowpack predictions and anticipated wildlife use (Christiansen and Low, 1970; Olson, 2009). Consequently, refuge managers sit on water boards

Table 4
Water rights held by the USFWS for use at Bear River MBR (74,000 acres, established 1928); (UDWRi, 2012).

Priority date	Water quantity[a]			Water source	Designated beneficial use[b]
	Amount	Units	Limit		
Approved applications to appropriate					
1907	0.500	cfs	20.42 af/yr	Surface Drains	Irrigation and Stockwater
1928	1000.000	cfs	425,771af/yr	Bear River	Waterfowl Habitat
1955	0.011	cfs	0.42 af/yr	Underground Well, Perry	Stockwater
1961	0.134	cfs		Underground Well	Stockwater
1991	3.689[c]	cfs	2666.250 af	Salt Creek	Irrigation, Fish Culture, Wildlife
1995	1.000	cfs	40 af/yr	Underground Drain	Wildlife
1995	1.040	cfs	4.0 af/yr	Stauffer-Packer Spring	Wildlife
1997	2.000	cfs		Surface Water & Underground Drains	Irrigation and Stockwater
Diligence claims					
1860	1.040	cfs		Stauffer-Packer Spring	Irrigation
1869	2.400	cfs		Unnamed Stream	Wildlife and Irrigation
1870	3.060	cfs		Dan Walker Spring	Irrigation
1870	0.560	cfs		Perry Spring Stream	Irrigation
1880	0.015	cfs		Unnamed Spring Stream	Stockwater
1880	1.000	cfs	51.16 af/yr	Unnamed Spring Stream	Irrigation and Stock
1881	1.000	cfs	17.2 af/yr	Unnamed Spring	Irrigation
1896	2.400	cfs		Unnamed Stream	Stock, Irrigation, Wildlife
1902	0.002	cfs		Unnamed Stream	Stockwater
1902	15.900	cfs	11,511.28 af/yr	Bear River	Waterfowl Habitat
1902	108.100	cfs	150,057 af/yr	North Bay Return Flow & Seepage	Irrigation, Wildlife, Storage
1902	4.810[c]	cfs	2000.000 af	Bear River	Irrigation
Underground water claims					
1869	1.000	cfs		Perry Spring Stream	Irrigation and Stockwater
1870	0.002	cfs	0.22 af/yr	Underground Water Drain (open)	Stockwater
1885	1.500	cfs		Underground Water Drain	Irrigation, Stock
1885	2.000	cfs		Underground Water Drain	Irrigation
1887	3.000	cfs		Underground Water Drain	Irrigation
1900	1.590	cfs		Underground Water Drain	Irrigation
1900	1.114	cfs		Underground Water Drain	Irrigation and Stockwater
1920	0.010	cfs	7.0 af/yr	Underground Water Well	Stockwater
Decreed water rights					
1896	7.370	cfs		East Slough	Stock, Irrigation, Other
1896	45.000	cfs		Black Slough	Irrigation and Other

[a] cfs = cubic feet per second, which is equivalent to 1.98 acre feet per day; af = acre feet; af/yr = acre feet per year, a limit stipulated by some water rights.
[b] Irrigation rights can be diverted only during the irrigation season (April–October). Stockwater rights can be used all year long, but all stock rights represent a small portion of overall rights. Waterfowl and wildlife rights may be used year round, unless otherwise limited.
[c] Water right was specified in acre feet per year, flow rate was calculated by authors.

with other water users representing the Lower Bear River and engage in discussions with PacifiCorp and canal managers as they plan reservoir and diversion operations each year. The alliances Bear River MBR managers have built with more senior water rights holders in the area will prove critical as the whole Lower Bear River region adapts to climate change.

4.3.3. The role of social linkages in managing scarce wetland water supplies

Because of the unpredictability of their water supply, refuge managers at Bear River MBR have done the most work in adapting to drought. Interviewees identified three ways Bear River MBR managers have been leaders in adapting to their position in an agriculture-dominated watershed: water management infrastructure and planning, participation in water rights decision-making processes, and communication with neighboring water users. Not only were Bear River MBR managers the first to construct a system of dikes and canals, they were also one of the first to develop detailed, wildlife-based water management plans and are active in sharing these plans with the community to garner local support for their efforts. Refuge managers completed a long-term Comprehensive Habitat Management Plan in 1997, and are currently updating their plan, according to the 15-year time-table set up by the CCP process (USFWS, 1997). The long-term plan is supplemented by annual habitat management plans that use shorter-term water forecasts to determine which of the refuge's wetland units will be inundated and how deeply according to water availability, wildlife use, and habitat goals (Olson et al., 2004; Olson, 2009).

Managers at Bear River MBR have demonstrated the most political involvement and communication with local water users, which is proving to be an effective strategy in adapting to water variability. Refuge managers recognize their water supply is intimately related to irrigation needs in Bear River's Lower Division. Diversions for irrigation not only deplete the river above the refuge, but during the irrigation season water in the Bear River is nearly exclusively irrigation return-flow. Being linked to agricultural water users makes the wetland water supply subject to the same forces that threaten agriculture: climate change and urban development. Bear River MBR managers have sought various opportunities to form alliances with agricultural water users as they address various issues at water board meetings and appeal new water rights applications. Because of this long history of drought adaptation, Bear River MBR managers may be better able to adapt to climate change, as they have already shown their ability to adapt to frequent drought-like conditions.

4.4. Case study comparisons – wetland water management adaptations in agriculture-dominated regions

Impoundment and diversion of water for irrigation connect Bear River wetlands to agricultural water use through the physical linkages of hydrology and water management infrastructure and the social linkages of joint action to navigate western water law and politics. The Law of the Bear River created opportunities for wetland managers to secure access to water through development of location-specific water rights portfolios and negotiated access to water. The reservoir-adjacent and irrigation-dependent wetlands at Bear Lake NWR and Cokeville Meadows NWR have the most reliable water supply, because they are upstream of major diversions and each are located at a critical water management nexus that provides them with water access under the current complicated Bear River legal and water infrastructure regime. The diked-delta wetland complex at Bear River MBR has the least reliable water supply because it is located downstream of all diversions at the nexus of the Bear River and the Great Salt Lake, where water that passes by is legally considered "wasted." The differences in hydrology and policy at each refuge have led USFWS refuge managers to pursue different ways to secure access to water that are appropriate for each refuge's contextualized reality.

At Cokeville Meadows NWR, managers acquired a portfolio of senior water rights and canal shares with lands purchased for the refuge. Bear Lake NWR managers negotiated access to very secure water supplies within their refuge without applying for water rights or owning water shares. Bear River MBR, the oldest and largest refuge in the system, has a large portfolio of water rights managers applied for and claimed over the years, but the largest of these rights is junior to most irrigation rights on the river, creating an unreliable supply. The security of all the refuges' water rights portfolios is intimately linked to the irrigation water storage and delivery system of the river; thus, threats to that system represent threats to the wetlands.

Despite differences in water supplies, refuge managers have made similar adaptations to the hydrologic and political context of this agriculture-dominated system. The first of these adaptations is recognition of wetland habitat values and the ways wetland protection is linked to agriculture. Second, refuge managers have been able to identify the direct source of water and the best means for gaining access to it, which varies by location. Finally, all refuge managers have built ties to the community of local water users through active participation in meetings, seeking public comment on management plans, and developing understanding of the context they are managing within. While the hydrology and policies of the Bear River are unique to some degree, the lessons learned here are applicable in other arid watersheds.

5. Discussion

Managing wetlands in arid, agriculture-dominated human-natural systems requires adapting to the contextualized position each wetland occupies, building a portfolio of water rights to accompany wetland land protection strategies, and understanding the infrastructure needed to create and maintain wetlands. This is no small task, but addressing these challenges gives wetland managers greater capacity to adapt to the intersecting forces threatening to increase water scarcity in many arid regions: drought, climate change, and urbanization.

5.1. Adapting to context presents opportunities for wetland protection and management

Impacts to wetland hydrology most often happen outside the boundaries of wetland management areas. Recognizing the history of upstream changes that have occurred is crucial to identifying threats to wetlands and pursuing potential mitigation strategies. This is especially true for agriculture-dominated regions with complex engineered systems that dramatically alter river hydrology. For example, recognizing that wetlands were created by irrigation practices allows managers to secure the water necessary to continue irrigating, address sources of contaminants, and identify opportunities for securing access to excess water supplies. These approaches have proven critical throughout the West where large-scale irrigation projects have created incidental wildlife habitat that entail new management challenges and opportunities (Lemly et al., 1993; Peck et al., 2004; Richmond et al., 2010). Across the U.S. as managers have identified the value of created reservoir-adjacent wetland habitat, they have negotiated arrangements with reservoir operators to manage water levels in ways that are beneficial to wetlands and other water users alike (Nishihiro et al., 2004; Pyrovetsi and Papastergiadou, 1992; Syphard and Garcia, 2001). Globally, delta wetland protection has often involved extensive, long-term water management and watershed-scale negotiations (Coleman et al., 2008; Pringle, 2001; Syvitski et al., 2009).

The impacts faced by the agricultural-linked wetlands described in these Bear River case studies and the opportunities for cooperation with other water users are common throughout the U.S. Participation in water user groups and community involvement allows wetland managers to gain knowledge of how water is used in their region and to develop relationships that are critical to adaptability (Sneddon et al., 2002; Walker et al., 2002). Understanding hydrologic interdependencies enables them to identify influential water users, opportunities for securing access to water, and how future threats to water supplies due to population growth and climate change will likely alter existing relationships (Liu et al., 2007b). These actions support wetland protection by helping managers respond to changes in the current water delivery system (e.g., shifts from agricultural to municipal use or improvements in water use efficiencies) that impact wetland water rights and access (Jackson et al., 2009; Richter et al., 2003), provide input on decisions about future water use, and collaborate to increase the joint water security of a region.

5.2. Securing access to water for wetlands requires diverse strategies

A critical step in managing water in agriculture-dominated systems is the assembly of a diverse, contextually-appropriate water rights portfolio. In such systems "wet water" is often unavailable for environmental uses during the irrigation season, when it is needed most (Baron et al., 2002; Jackson et al., 2001). Therefore, acquiring access to water for wetlands requires sustained and diverse strategies to acquire rights with senior priorities or to make agreements with senior water rights holders. This includes purchasing water rights with lands, buying shares in canal companies, forging agreements for shared use of senior water rights, and negotiating drought contingency plans. Multiple sources of water, (i.e., from streams, canals, and groundwater) provide a buffer against drought, as unpredictability in one source may be offset by utilization of another. Assembling a portfolio of rights is only possible through an understanding of regional and local water use institutions, and active monitoring of new opportunities and threats to water access.

5.3. Protecting against drought requires infrastructure, planning, and communication

Protecting wetlands against drought in agriculture-dominated systems requires managing water to buffer wetlands against fluctuations that occur according to irrigation demands (Nielsen and Brock, 2009; Pringle, 2000). Once water is secured, it must be managed to maintain habitat values. The most common form of wetland water management is through a system of canals and dikes that impounds water when it is available and draws it down slowly as scarcity sets in, or bypasses water during large floods. However, water management infrastructure is only as effective as the management plan behind it. Ecological risks accompany impoundment of wetlands, and effective water management requires integrating an understanding of ecological needs with a location-specific water management plan (Zacharias et al., 2003). Such plans may help managers adapt to annual and long-term water supply fluctuations and provide a means for communicating with other water users.

Wetlands are critical components of agriculture-dominated human-natural systems and protecting them from drought is only possible through recognition of the physical and political linkages between wetlands and agricultural water users. The details of these linkages are location-specific and effective management occurs when managers have a contextually grounded plan for accessing and managing water. Managing wetlands in the West requires water, and because most wetland protection policies are focused on protecting land rather than water sources, federal managers must pursue unique strategies for securing water supplies that require they understand watershed and local hydrologic and policy contexts. This understanding involves: 1) recognizing the source of wetland water, especially in relation to other water users' demands and return flows; and 2) researching water policy in the region to see where opportunities exist for acquiring access to water. Adaptive strategies include: 1) buying, applying for, and claiming use of water rights (the more senior, the better); 2) building infrastructure to capture and divert water when it is available; and 3) maintaining an active role in the local community of water users. Case studies such as those presented here provide valuable lessons in strategies for keeping wetlands wet under future conditions and uncertainties related to water availability.

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