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A New Era of Big Infrastructure? (Re)developing Water Storage in the U.S. West in the Context of Climate Change and Environmental Regulation

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ABSTRACT: For most of the 20th century, water policy in the western United States was driven by the construction of large dams and other big infrastructural projects to increase water storage. By the 1980s, however, most optimal sites were developed or protected through conservation policies. Today, climate change and growing water demands pose new challenges for water management. Consequently, policy-makers are once again advocating for water storage. In the U.S. and other developed countries, this return to supply-side solutions is manifesting in auxiliary infrastructural projects such as dam augmentation and aquifer storage and recovery (ASR). We argue that the return to a high-modernist reliance on big infrastructure is not limited to developing countries and illustrate the rise of auxiliary infrastructure using two case studies in California and Oregon. Our analysis suggests these auxiliary infrastructural projects are appealing to water managers because they purport to accommodate the demand for new water-governance strategies while working within the limitations imposed by past infrastructural development and environmental policy. Nevertheless, increasing storage capacity alone is insufficient for water management in the context of climate change, for demand-side strategies must also be pursued.

KEYWORDS: Political ecology, climate change, adaptation, conservation policy, water governance, infrastructure

INTRODUCTION

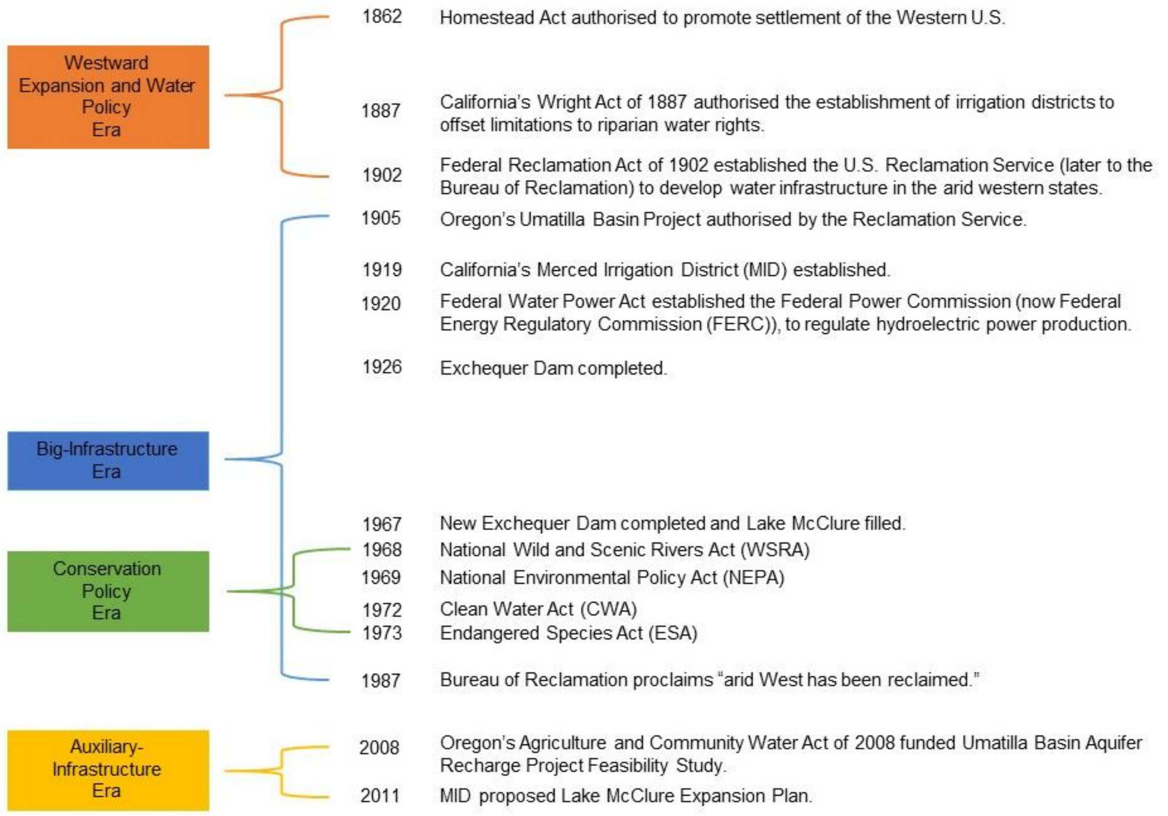
For most of the 20th century, water policy in the western United States was driven by reclaiming water to support development in arid lands, particularly through the construction of large dams and irrigation infrastructure (Worster, 1985; Billington et al., 2005). Here, we are using the International Commission on Large Dams definition of a large dam as a structure greater than 15 m in height (ICOLD, 2017). These water infrastructural projects were critical to the economic development of the western U.S., especially in the agricultural and energy sectors (Sauer, 2010). Since the 1980s, however, as noted by Billington et al. (2005), "New large dams were just not going to be built any longer, at least not at the fervent pace of the big dam era" (412). The World Commission on Dams notes the pace of dam building in North America and Europe has notably declined since the 1980s, even while the number of new dams continues to increase in Asia, Africa, and South America (WCD, 2000). This pause in project development resulted from several political-ecological factors. First, most of the ideal big-infrastructural project sites had already been developed, leaving less optimal options for future exploitation (Graf, 1999). Second, the rise of the environmental movement in the 1960s and subsequent creation and implementation of federal policies for conservation and environmental quality that influenced water resources also contributed to the decline of big reclamation project developments [i.e. the National Wild and Scenic Rivers Act of 1968 (WSRA), the National Environmental Policy Act of 1969 (NEPA), and the 1973 Endangered Species Act (ESA)] (Pisani, 2003). These laws posed institutional barriers for new infrastructural project development by mandating that environmental impacts of federally funded, regulated, or licensed dams factor into project feasibility and approval (see Figure 1). For example, in the 1970s, the planned construction of the Auburn Dam on California's North Fork of the American River was halted because of concerns about the impacts on ecological and recreational values, as well as issues with cost and safety (Duffield, 1980). Environmental laws even provide the opportunity to remove some extant infrastructure, such as the ground-breaking plan to remove four multipurpose dams on the Lower Klamath River to benefit fisheries (Gosnell and Kelly, 2010). A third factor that limited new development of big infrastructural projects was the neoliberal decentralising of economic policies of the Reagan Era which cut government expenditures on infrastructure and utilities (Holden, 1980). Against this backdrop, the Bureau of Reclamation (Burec) declared in 1987, "[T]he arid West essentially has been reclaimed. The major rivers have been harnessed and facilities are in place or are being completed to meet the most pressing current water demands and those of the immediate future" (Burec, 2013: 2). With the decline of new large surface-water reclamation projects in the latter half of the 20th century and improvements in groundwater pumping technology, many regions developed more extensive reliance on groundwater withdrawals for irrigation water supply, such as in the Central Valley of California (Konikow, 2013).

In recent decades, however, water availability in the western U.S. has been a topic of increasing concern due to dwindling supplies resulting from drought and groundwater depletion coupled with the increasing population demands and agricultural intensification (Anderson and Woosley, 2005). Of the 11 states with the fastest-growing populations, eight are in the U.S. West (Albrecht, 2008). This rapid population growth is a major driver of increased water demand in the region. Moreover, climate change poses a major threat to water resources through increased evapotranspiration along with altered spatiotemporal precipitation patterns, in particular the reduction of snowpack and changes in the timing of spring runoff (Jiménez Cisneros et al., 2014). Although physical water scarcity (an absolute lack of water) is likely to remain uncommon, economic water scarcity (an inability to meet all demands for water using the available supply) will be exacerbated by climate change (Brown and Matlock, 2011).

Issues of water availability and climate change are not unique to the United States, but are instead global concerns. As such, today a resurgence of high-modernist reliance on big infrastructure for water management and energy production is seen around the world (Shah and Kumar, 2008). By 'high modernism', we mean a state-centred approach to development and social organisation (Forest and Forest, 2012). In developing countries many of these projects are taking form as large dams, increased deep-well drilling, and extensive water conveyance infrastructure. These developments are similar to those of the 20th century western U.S. For example, the tallest dam in India (the multipurpose Tehri Dam completed in 2006) was constructed to supply irrigation water and generate hydroelectric power (Sharma, 2009). Other examples of recent big-infrastructural projects in the developing world are China's South-North Water Transfer Project (Zhang, 2009) and the United Nation's 'Green Climate' funding for dams in Nepal, Tajikistan, and the Solomon Islands (UNGCF, 2017). In developed countries, however, new supply-side projects are constrained by the lack of available suitable sites and by the presence of a complex array of natural resource regulations and conservation policies. Many new infrastructural projects developed or proposed during the resurgence of supply-side water management in the U.S. are what we call 'auxiliary' projects. Instead of developing 'new' water sources through reclamation using traditional engineering such as construction of new dams and inter-basin transfers or rampant well-drilling, these auxiliary projects leverage existing infrastructure to increase water storage capacity. Examples of auxiliary infrastructural projects include dam augmentation by increasing dam height and aquifer storage and recovery (ASR) through the artificial recharge of deep and shallow aquifers. These storage projects explicitly aim to address issues of water availability while implicitly providing climate change adaptation by seemingly working within the framework of environmental regulation.

We argue the return to big infrastructure in not limited to developing countries but instead includes path-dependent auxiliary supply-side infrastructural projects in developed countries. This trend of increasing reliance on auxiliary infrastructure is demonstrated by the numbers of recent and proposed dam augmentations and ASR projects in the U.S. and other developed countries. Moreover, dam augmentation and ASR are emerging as significant project proposals and/or institutional responses to climate change and water availability issues. To illustrate this trend, we describe two case studies from the U.S. West, the Merced Irrigation District's Lake McClure Expansion Plan in California (a dam augmentation project) and the Umatilla Basin Aquifer Recharge Project in Oregon (an ASR project). We also discuss the limitations of the auxiliary infrastructural approach stemming from its focus on supply-side water management at the expense of demand management.

Figure 1. Eras influencing water governance and big infrastructure in the Merced and Umatilla basins.



1862	Homestead Act authorised to promote settlement of the Western U.S.
1887	California's Wright Act of 1887 authorised the establishment of irrigation districts to offset limitations to riparian water rights.
1902	Federal Reclamation Act of 1902 established the U.S. Reclamation Service (later to the Bureau of Reclamation) to develop water infrastructure in the arid western states.
1905	Oregon's Umatilla Basin Project authorised by the Reclamation Service.
1919	California's Merced Irrigation District (MID) established.
1920	Federal Water Power Act established the Federal Power Commission (now Federal Energy Regulatory Commission (FERC)), to regulate hydroelectric power production.
1926	Exchequer Dam completed.
1967	New Exchequer Dam completed and Lake McClure filled.
1968	National Wild and Scenic Rivers Act (WSRA)
1969	National Environmental Policy Act (NEPA)
1972	Clean Water Act (CWA)
1973	Endangered Species Act (ESA)
1987	Bureau of Reclamation proclaims "arid West has been reclaimed."
2008	Oregon's Agriculture and Community Water Act of 2008 funded Umatilla Basin Aquifer Recharge Project Feasibility Study.
2011	MID proposed Lake McClure Expansion Plan.

BACKGROUND

Anthropogenic climate change is expected to have significant impacts on global water resources. These impacts include increased evapotranspiration, resulting from higher temperatures, as well as a likely increase in the frequency and intensity of drought. In snowmelt-dominated river systems like those in the U.S. West, higher winter temperatures will result in reduced snowpack accumulation, with less snowmelt available to contribute to river discharge during the summer (Jiménez Cisneros et al., 2014). During the summer growing season, the region receives relatively little precipitation when water demand by both agriculture and ecosystems is greatest, making snowpack essential for maintaining river flow and supplying water (Bales et al., 2006). Significant hydrologic changes have already been observed in Western U.S. snowmelt-driven rivers for the period spanning from 1950 to 1999, including increases in winter temperature of 0.28-0.43°C per decade, decreases in normalised snow-water equivalent of 2.4-7.9% per decade, and shifts in peak streamflow timing by 0.3-1.7 days earlier per decade (Barnett et al., 2008).

Surface-water supplies are highly sensitive to climate variability and change while groundwater is less sensitive to climatic factors in the short term, especially fossil groundwater that had accumulated over millennia (Tague et al., 2008). In the long term, however, drier and hotter conditions will result in reduced groundwater recharge and a total decline in aquifer levels (Green et al., 2011). Furthermore, limited surface water availability often leads to the increasing exploitation of groundwater, as was the case during the recent California drought (Howitt et al., 2015). Moreover, groundwater extraction lowers the regional water table and makes less water available for streams and springs. Climate change, therefore, potentially leads to groundwater scarcity over both short and long time-scales and reduces the supply of surface water. These hydrologic changes in both surface water and groundwater resulting from climate change are likely to intensify economic water scarcity in the U.S. West and exacerbate conflict among different water sectors.

With scenarios like the aforementioned in mind, there is a widely recognised need for climate-change adaptation in water governance. Adaptation measures can focus either on increasing water supply or reducing demand, and include either 'hard' (infrastructure) or 'soft' (institutional) options (Sovacool, 2011). In some cases, water managers have advocated for institutionalisation of demand-side water efficiency and conservation measures. For example, California's new state-wide water conservation plan includes recommendations for implementing new urban water use targets, prohibiting wasteful water practices, requiring municipal water suppliers to develop water shortage contingency plans, and strengthening agricultural water use plans (CDWR, 2017). One reason why water conservation measures are difficult to enact in California is the state's fiscal and legal structure imposed by Proposition 218. Passed in 1996, this policy requires that fees charged by local agencies be explicitly linked to the cost of the service provided (Hanak et al., 2014). Proposition 218 limits the ability of water utilities to charge block rates based on water use. Other western states have different legal structures that incentivise water conservation. For example, the Oregon Water Trust establishes a market for water rights, potentially allowing senior water-rights holders to sell their rights to preserve instream flows (Neuman, 2004). Nevertheless, the Oregon Water Trust and many water conservation measures in other western states are voluntary and limited.

Although all types of adaptation have been advocated, the culture of many water-governance institutions is dominated by an engineering perspective, resulting in path-dependent supply-side infrastructural approaches as the main focus (Gleick, 2000; Pahl-Wostl et al., 2008). Storage is a supply-side infrastructural option already widely used, making it attractive to decision-makers as a climate-change adaptation strategy (Brown and Lall, 2006). For instance, in a report for the International Water Management Institute, McCartney and Smakhtin (2010) argue, "Water storage (in all its forms) has a key role to play for both sustainable development and adaptation to climate change" (8). In the U.S. West, Oregon's Integrated Water Resources Strategy (OWRD, 2012) states, "Storing water, via built and natural systems, is important for meeting Oregon's water needs" (55). The California Climate Adaptation Strategy also recommends the expansion of surface water storage as a potential solution for increasing climate-change resilience (CNRA, 2009).

Globally, new water-storage projects are being implemented in the traditional form of large dams, especially in developing countries. Dams are grounded in spatiotemporal shifts of water availability to suit human needs by storing water in reservoirs during periods of high flow for use during low-flow periods (Keller et al., 2000). These dam projects are often promoted as advancing economic development projects, not only through hydroelectric power, but also through increased resilience to economic water scarcity, with climate change as an explicit or implicit driver of that scarcity (Keller et al., 2000; Brown and Lall, 2006).

In the U.S. West, new dam construction proposals are also on the negotiating table with policy-makers (i.e. the Bear River in California, the Lower Yellowstone River in Montana) (Snider, 2010; Brown, 2015). In large part, however, new water-storage projects in developed countries are not taking the form of new large dams, because most optimal sites have been developed or protected through conservation policies. Thus, the unconventional water storage augmentation that we call 'auxiliary' infrastructure development is emerging as a water-storage solution based on big infrastructure familiar to water managers and consistent with the techno-managerial culture at many agencies (Clement, 2014).

One example of auxiliary storage is dam augmentation, in which the height of an existing dam is raised. Examples abound of recent proposed and implemented dam augmentation projects in the U.S. and other developed countries. For example, the CALFED Bay-Delta Program, a department within the California state government that works with federal agencies to resolve water problems in the Sacramento-San Joaquin River Delta, aims to increase surface water storage in California through a series of proposed dam constructions or augmentations. One of the proposed CALFED projects is enlarging the Los Vaqueros Reservoir in Contra Costa County (Minton, 2008). Another proposed CALFED project would raise the height of California’s Shasta Dam by 2 to 5.6 m in order to increase water storage for irrigation by submerging an additional 433 to 1060 m of the McCloud River upstream of the current reservoir, consequently flooding currently preserved Winnemem Wintu sacred and ceremonial sites (Dallman et al., 2013). In Colorado, efforts are underway to expand Denver Water’s Gross Reservoir in Boulder County, which is supplied by flows from the Fraser River, on the western side of the Continental Divide, that are diverted through a tunnel to the eastern side (Goodland, 2016). In addition to these U.S. projects, dam augmentation projects are common in other developed countries, such as the recent expansion of the Chaffey Dam in New South Wales, Australia, for increased water storage (WaterNSW, 2017). These example projects demonstrate that developed countries are seemingly finding it more feasible to expand the height of existing dams to increase water storage rather than to build new dams.

Another example of auxiliary infrastructure, ASR, is based on artificial recharge of groundwater. ASR projects are similarly experiencing a surge of interest in developed countries. The number of ASR projects in the US has increased from less than ten wells in the 1960s to over 200 wells after 2010, including projects in Arizona, California, Colorado, Idaho, New Mexico, Nevada, Oregon, South Dakota, Utah, and Washington (Bloetscher et al., 2014). For example, El Paso Water Utilities in Texas uses reclaimed wastewater to recharge the Hueco Basin aquifer, and has recharged approximately 74.7 million cubic metres (Mm^3) in 18 years (Sheng, 2005). The Los Angeles County Waterworks District in Antelope Valley has recharged over 3.7 Mm^3 to the regional aquifer (Rydman, 2012). Australia is a leader in ASR development, with over 4 Mm^3 of annual recharge in South Australia alone (Martin and Dillon, 2002). ASR projects have also been implemented in Canada, Israel, England, and the Netherlands (Pyne, 1995). Improved technology and increasing concern about declining aquifers are driving an expansion of ASR projects.

Both types of auxiliary infrastructural projects retain the basic reservoir function of capturing and storing water for later use. These storage mechanisms alter the spatial and temporal distribution of the water resource while seemingly generating a smaller 'footprint'. In the case of dam augmentation, these projects enlarge the pool of an existing reservoir, instead of inundating a free-flowing river segment and flooding an entire canyon and its lands to create a new reservoir. ASR’s smaller footprint comes in the form of storing more water, transported from another source, into a local aquifer. The smaller footprint comprises part of the rationale for these projects, because it allows for more efficient use of an already highly developed landscape. In addition, the projects purport to have less environmental impact than the construction of new infrastructure, which allows them to work within the constraints of environmental regulation. Because auxiliary projects nominally ameliorate many of the negative impacts of traditional water infrastructural development while still fitting within the supply-side engineering comfort zone of water governance agencies, they are likely to become an increasingly common tool for climate-change adaptation in the developed world.

CASE STUDIES

We selected two case studies from the U.S. West to illustrate an emerging trend of auxiliary water-supply infrastructure as a climate-change adaptation strategy. Both cases are located in semiarid regions dominated by big infrastructure developed for irrigated agriculture in the 20th century. Moreover, these two auxiliary projects depend on extant infrastructure. The first case is the Merced Irrigation District's Lake McClure Expansion Plan in California, an example of a dam augmentation project. The second case, an example of ASR, is the Umatilla Basin Aquifer Recharge Project in Oregon. Despite the similarity of the two case studies as auxiliary water-storage projects, their differing physical and institutional settings also demonstrate the importance of local context in determining the nature of water governance.

Merced Irrigation District's Lake McClure expansion plan

The Merced River flows from Yosemite Valley in California's Sierra Nevada mountain range into the San Joaquin Valley, forming part of the greater San Joaquin Hydrologic Region. The climate within the watershed ranges from alpine to Mediterranean to semiarid zones (Stine, 1996). The average annual runoff is over 1.2 billion cubic metres (Bm^3) (FERC, 2012). The average maximum temperature in the lower basin is 24°C, and the average minimum temperature is 8°C. The warm conditions in the region make the Merced River watershed an ideal location for agricultural production.

To support the development of an agricultural industry in the region, California's Wright Act of 1887 authorised the establishment of irrigation districts in the San Joaquin Valley (Parsons, 1986). The Merced Irrigation District (MID), one such district, became a legal entity in 1919. In 1926, MID completed Exchequer Dam, filled Lake McClure, diverted water to crops, installed an electricity-generating facility, and began selling hydropower to consumers in the region. Over the next 40 years in the valley, the agricultural industry flourished and populations grew, increasing demands for both irrigation and energy. To meet those demands, MID built the New Exchequer Dam in 1967, roughly tripling its power generation and water storage capacity (MID, 2008). The current storage capacity of the reservoir is 1.26 Bm^3 and the dam has an installed capacity of 94.5 MW, generating 316 million KWh annually (FERC, 2012). Irrigation and hydropower are the predominant uses sustained by the reservoir's reclaimed waters, though it provides recreational, domestic, and environmental uses as well (USDOI, 2012).

MID diverts around 641 Mm^3 of water annually from Lake McClure into the irrigation system, supplying roughly 2200 farmers encompassing 55,847 irrigable hectares. A complex system of dirt-lined and concrete canals as well as piping span a total of 1328 km, delivering water to over 4000 gates. The area is considered to be 'America's Salad Bowl' and produces thirsty row crops including alfalfa, cotton, sweet potatoes, and tomatoes. In recent years, many farmers switched to high market value perennial fruit- and nut-bearing crops (i.e. almonds, grapes, pistachios, peaches, walnuts and apricots) (Merced, 2011, USDOI, 2012). Merced County's leading commodity is milk (a water-intensive product) for which it is the second largest producer in California's dairy industry (Agweb, 2015). Beef cattle and poultry comprise the remaining top commodities in the district (Merced, 2011).

In 1987 and 1992, Congress and Presidents Reagan and H.W. Bush respectively designated the stretch of river upstream of Lake McClure Reservoir as a National Wild and Scenic River due to the Merced's 'Outstandingly Remarkable Values' or ORVs (USDA, 1991; FOR, 2008). Approximately 196 km of the Merced River flowing from Yosemite Valley through Yosemite National Park to Lake McClure are protected under the Wild and Scenic Rivers Act of 1968 (WSRA) (RMC, 2012). Designation under the WSRA ensures protection of the free-flowing uncontaminated waters, endangered species habitat for the bald eagle and endemic limestone salamander, the preservation of historic mining and railroad sites, access to kilometres of hiking and biking trails, and a tourism industry centred on white-water boating and fishing opportunities. The designation purportedly provides permanent protection for the Wild and Scenic section of river and prohibits any development that would otherwise jeopardise the ORVs (FOR, 2013).

The average daytime temperatures of California increased by about 0.06°C per decade since 1920, with the greatest warming in the Sierra Nevada (Moser et al., 2009). The amplified warming in the Sierra Nevada is significant for the Merced River because its flows are dependent on mountain snowpack. Sierra Nevada snowpack is projected to shrink by 30 to 70% by 2099, with drier, higher-warming scenarios putting that number as high as 90% (Kahrl and Roland-Holst, 2012). Increased temperatures are already resulting in decreased snowpack and increased demands for irrigation water and energy for cooling, a scenario projected to persist and intensify in the Merced Basin (Kiparsky et al., 2014). California experienced drought conditions from 2007 to 2009 and then again from 2011 to 2016. In fact, a recent study found that, during the most recent California drought, the climate change-induced combination of "extremely warm and dry conditions have led to acute water shortages, groundwater overdraft, critically low stream-flow, and enhanced wildfire risk" (Diffenbaugh et al., 2015: 3931).

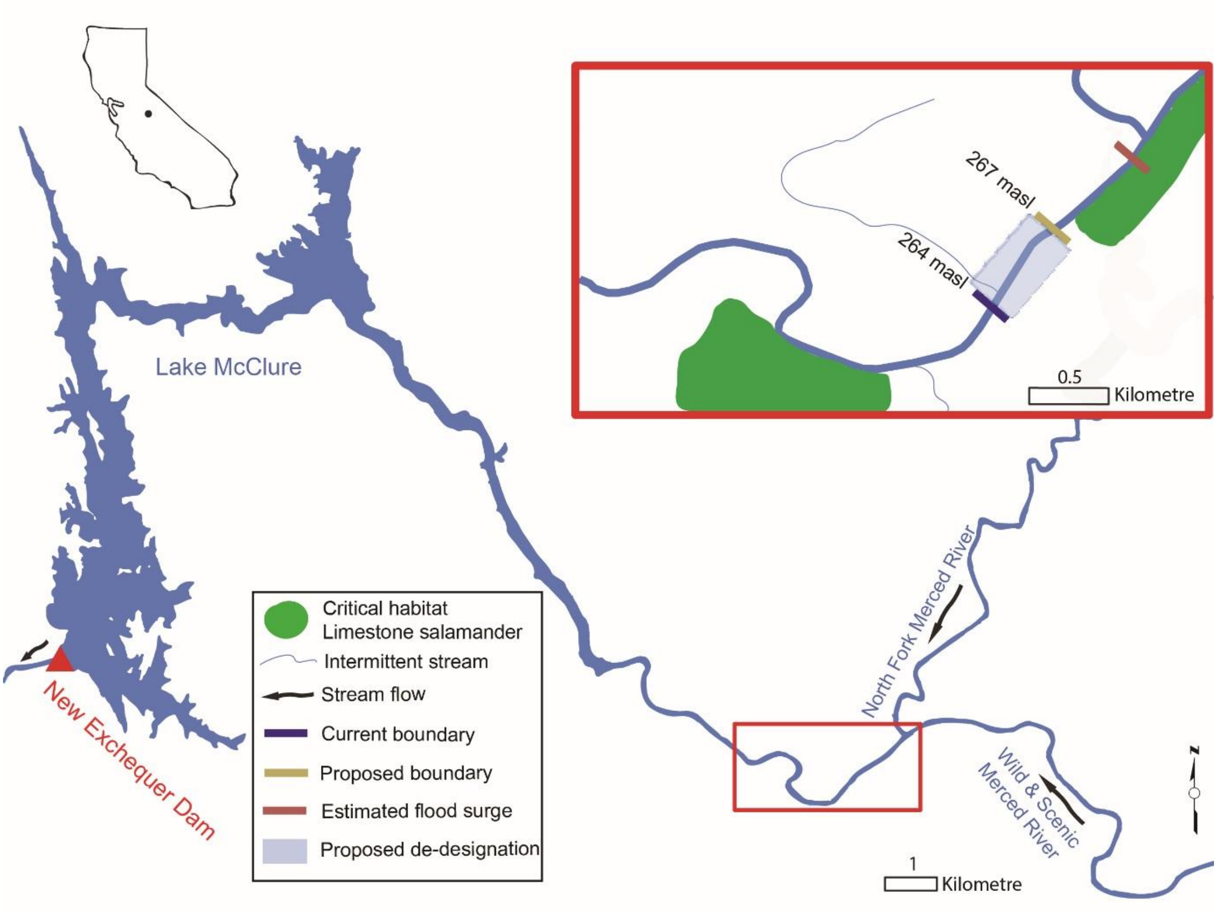
These severe conditions which threaten California’s agriculture-based economy spawned a series of dam expansion and construction proposals across the state, including the Bureau of Reclamation’s proposals to construct the Temperance Flat Dam on the San Joaquin River, raise Shasta Dam on the Sacramento River by 5.6 m, and raise Pine Flat Dam on the Kings River by 2 m (KRCD, 2016); and the Nevada Irrigation District’s proposed Centennial Dam on the Bear River.

Faced with sustained drought, in 2011 MID devised the Lake McClure Expansion Plan in similar attempts to increase reservoir storage capacity to meet increasing energy and irrigation demands. The project would raise the New Exchequer Dam gated spillway by 3 m, allowing for the capture of up to an additional 86 Mm^3 of water during 'wet years'. As pictured in Figure 2, the increased capacity would temporarily raise river water levels in an approximately 549-m segment of the Merced to reach an elevation of 267 metres above sea level (masl). The upsurges are projected to last two to eight weeks and occur in three-year intervals (FOR, 2016).

By utilising extant infrastructure, the expansion plan could potentially augment water supplies for irrigation while reducing demand on groundwater pumping in the region, which is already experiencing severe drawdown of groundwater wells (Famiglietti et al., 2011). In addition, the increased elevation of the reservoir could increase the capacity for hydropower production by up to 10,000 MWh per year (FOR, 2016). This expansion plan could be achieved at a relatively low cost (estimated at USD40 million) compared to the construction of a new dam elsewhere in the area.

While the reservoir expansion has the potential to store more water in wet years, evaporation losses due to increased temperatures would be substantial, potentially neutralising the benefit of the expansion. Among basin water users, additional water storage may create a false sense of security that leads to a disincentive to conserve water. This issue highlights the risk of relying on technology rather than addressing the larger issues of climate change (Tuinhof et al., 2002). Moreover, by raising the flood gates to 3 m, spillway flood protection is reduced to 0.3 m, creating a potential flood hazard (MERG, 2013) in an environment that may be prone to more frequent and severe floods due to changing temperature and precipitation regimes (RMC, 2012; FOR, 2016).

Figure 2. Lake McClure expansion plan boundary dispute (map by Denielle Perry).



Because of the hydropower-producing facility at New Exchequer Dam, the Federal Energy Regulatory Commission (FERC) is tasked with regulating the operation of the dam. Raising the reservoir's elevation would conflict with the current FERC license which requires that MID operate the dam with a spillway at the 264-m elevation. It is precisely at this elevation that the Wild and Scenic Merced River's downstream boundary is located. This specific maximum pool elevation was set in accord with WSRA boundary regulations. Therefore, to implement the changes, Congress must agree to redraw the boundaries of the designated Merced Wild and Scenic River section to allow FERC to conduct feasibility studies on the proposed dam expansion plan (MERG, 2013).

The irrigation district mobilised its political power through California's 10th Congressional District House Representative, Republican Jeff Denham, and his introduction of bill HR 869 "to clarify the definition of flood control operations for the purposes of the operation and maintenance of Project No. 2179 on the Lower Merced River" on March, 2 2011 (H.R. 869, 2011). Between 2011 and 2015, five similar stand-alone bills or riders were introduced to Congress. To date, none of them has successfully passed both houses; however, what has essentially become a boundary dispute continues.

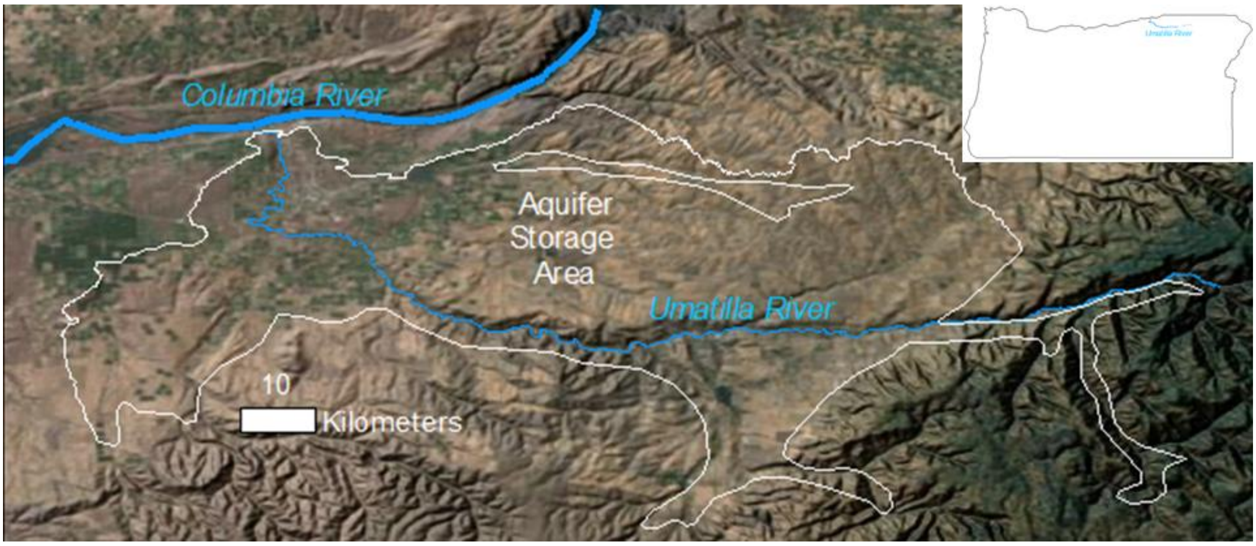
The reluctance of Congress to redraw the boundaries rests in the controversial nature of the project. A boundary alteration of this sort would be the first time that a Wild and Scenic River designation was changed in order to allow for reservoir expansion. As it stands, the WSRA application on the Merced River prohibits the flooding of endangered species habitat, 8 km of hiking and biking trails, and the free-flowing stretch of river utilised by private recreationalists, and commercial white-water boating and angling industries.

Careful consideration must be made in permitting such a project due to the implications for other WSRA protected rivers that have similar potential for auxiliary-infrastructure development at extant dam structures both in California (i.e. the Feather, Eel, and Kings rivers) and across the U.S. (FOR, 2016). While increasing reservoir storage may be a viable option in some cases, the relatively small gain in storage projected for this expansion plan does not warrant the trade-off of undermining the integrity of hard fought conservation legislation on the relatively few rivers (208 in 2016) that are protected by the WSRA (Rivers, 2016). Instead, increasing water conservation efforts, lining kilometres of dirt canals, land-use changes, and crop conversion may provide more viable, long-term options in this case. The advantage of water conservation is that it does not threaten protected river segments and is sustainable in the context of climate change, unlike the Lake McClure Expansion Plan.

Umatilla Basin Aquifer Recharge Project

The Umatilla River is a tributary of the Columbia River in north-central Oregon (Figure 3). The Umatilla Basin is underlain by the Columbia River Basalt Group, which serves as a deep consolidated rock aquifer (Hogenson, 1964). The basin has a semiarid continental climate, with average temperatures ranging from 1°C in winter to 23°C in summer and average annual precipitation of approximately 25 cm (WRCC, 2016). Despite the semiarid climate, large-scale irrigation has allowed for the emergence of the Umatilla Basin as a leading agricultural area, with major crops including wheat, barley, canola, peas, alfalfa, potatoes, corn, melons, beans, and poplar plantations (NRCS, 2005).

Figure 3. Setting of the Umatilla Basin (map by Sarah Praskievicz).



The Bureau of Reclamation's Umatilla Basin Project, originally authorised by the Federal Reclamation Act of 1902, consists of a series of dams, canals, and pumping plants on the Umatilla River and its tributaries, providing a full irrigation supply to 6880 hectares (ha) of land and a supplemental supply to an additional 5361 ha (Stene, 1993). This surface-water supply, however, is insufficient to supply all the irrigable land in the basin, which resulted in a turn to intensive groundwater extraction (OWRD, 2003). Over the past several decades, with improvements in groundwater pumping technology, farmers have extracted fossil groundwater up to 27,000 years old from the basin's basalt aquifers, resulting in over 100 metres of groundwater decline since the 1950s and the declaration of four critical groundwater zones in the basin (UCCGTF, 2008). Irrigated agriculture in the Umatilla Basin therefore relies to a large extent on groundwater supplies that are not sustainable at the current rate of withdrawal.

Current supplies of surface water and groundwater in the Umatilla Basin are likely to be further stressed by climate change. In an Oregon Climate Change Research Institute (OCCRI) report, Vynne et al. (2010) projected future climate change in the Umatilla Basin for the 2040s and 2080s using three models and found expected increases of average summer temperature of up to 6-7°C, decreases of summer precipitation of up to 30%, decreases in snow-water equivalent of up to 50%, and a shift in the Umatilla River hydrograph to higher winter and lower summer discharge. These effects of decreased growing-season water supply and increased evaporative demand will negatively impact both the availability of supplies of surface water from the Umatilla River and the recharge rate of the Umatilla Basin Aquifer.

As a proposed solution to the basin's water-scarcity problems, the Umatilla Basin Water Coalition – an intergovernmental entity consisting of Umatilla and Morrow counties, the Westland Irrigation District, the County Line Water Improvement District, and the Confederated Tribes of the Umatilla – is in the process of implementing the Umatilla Basin Aquifer Recharge Project (UCCGTF, 2008). When fully implemented, the project will divert approximately 196 Mm^3 of water from the Columbia River during winter, the wet season in the Pacific Northwest (Ziari, 2009). The diverted Columbia River water will be transported to a recharge zone of sand and gravel to allow for infiltration into a shallow alluvial aquifer. Of this infiltrated water, the goal is for approximately 140 Mm^3 to be used directly for irrigation by farmers during the following growing season. An estimated 33 Mm^3 will augment Umatilla River summer discharge via return flow from the shallow aquifer. The remaining water will be injected into the deep basalt aquifer for long-term storage (IRZ Consulting, 2009). The Umatilla Basin Aquifer Recharge Project is an example of ASR, a water-management strategy in which aquifers are passively or actively recharged by surface water (Pyne, 1995).

The rationale for the Umatilla project is that it provides a solution for the basin's water availability problems with purportedly positive impacts for both farmers and the environment. The project essentially shifts supply of water both spatially and seasonally to better serve the needs of irrigation and ecology. Because the Columbia River is much larger than the Umatilla River, larger quantities of water can be withdrawn from the Columbia without affecting hydrological or ecological function. Moreover, because discharge is much higher in the winter than during the dry summer, there is substantial benefit perceived in withdrawing water during winter for later use during the growing season. These spatiotemporal water displacements are typical of conventional water governance strategies such as interbasin transfers (which transport water from a place of relative abundance to a place of relative scarcity) and dams (which store water during wet periods to be used during dry periods). Instead of storing water in an open reservoir, however, the Umatilla project uses aquifers.

There are several stated benefits to this approach. First, aquifer storage has advantages over surface reservoirs in that evaporative losses are far lower and they require less land area (Khan et al., 2008). Second, the infiltration process into the shallow alluvial aquifer performs an important water-quality function by filtering the water through gravel and sand. This filtering is vital to the success of the overall project, as any injected water is required to meet drinking water-quality standards so as not to degrade the resource (Pavelic et al., 2007). Also, filtering removes sediment that could otherwise clog the pores of the deep aquifer, reducing its storage capacity. Third, the connectivity between surface water and groundwater allows for Umatilla River baseflows to be supplemented by water stored in the shallow aquifer, which could significantly benefit the river's populations of Chinook and Coho salmon. Because of the project's perceived benefits for salmon, the Umatilla tribe supports the project, as do non-profit organisations such as Salmon for All (SFA, 2013). Finally, the active injection of water into the deep aquifer, after the filtering process by the shallow alluvial aquifer is complete, could potentially mitigate or even reverse the groundwater decline in the basin, thus improving long-term storage and sustainability of water supplies (Bouwer, 2002).

Although the Umatilla Basin Aquifer Recharge Project was not explicitly motivated by concerns about climate change, but rather by more general concerns about decreasing water supply and increasing demand, climate change has been acknowledged as one of the driving forces for water scarcity in the region. After signing the Agriculture and Community Water Act of 2008 (SB 1069), which funded the Umatilla Basin Aquifer Recharge Project feasibility study, then-Governor Ted Kulongoski said, "it sets us on a course in which we begin to address water shortages throughout Oregon – shortages that are the legacy of overuse, and even more worrisome, the single greatest consequence of global warming" (OSA, 2008: 1). Increasing water supplies through storage is positioned as a climate-change adaptation strategy that makes the region more resilient to future shortages in both surface water and groundwater.

The scale of the Umatilla Basin Aquifer Recharge Project is unusually large, but ASR has also been implemented on such a scale in other countries such as Australia and India (Dillon et al., 2009). ASR projects are especially attractive to water managers in the arid parts of the Inland Northwest of the US, where water availability is highly seasonal, the geologic setting is favourable because of the large storage capacity of basalt aquifers, and there is motivation to pursue water-management strategies that will benefit economically and culturally valuable species such as salmonids. In addition to the Umatilla project, similar aquifer recharge projects are in the design, construction, or evaluation stages in Idaho and Washington (Banse, 2016). Although ASR projects have been implemented in developing countries, they have been more common in countries like Australia and the United States, where existing large-scale groundwater pumping and irrigation infrastructure are leveraged to make the projects more affordable (Pyne, 1995). One water storage entity is as little as 11 m^3 per person in the poorest parts of Africa, but 6000 m^3 per person in North America (Jury and Vaux, 2005).

The Umatilla project and many other ASR projects rely on surface water from rivers as the source of aquifer recharge, but other sources can be potentially used. For example, source waters could include stormwater, reclaimed wastewater, and desalinated water (Ward and Dillon, 2011). Use of a passive infiltration area, as in the Umatilla project, can potentially improve the water quality by filtering through unconsolidated materials so that these water sources are suitable for irrigation or other uses (Dillon et al., 2006). Incorporating these auxiliary sources into ASR projects has the potential to make the projects more attractive by using water that is inappropriate for other uses.

ASR is an exemplar of the auxiliary water-storage technologies that are becoming increasingly common, especially in developed countries, as implicit climate-change adaptation strategies. The higher prevalence of ASR in developed countries is a function of its path-dependence on existing groundwater and energy infrastructure needed to withdraw and distribute groundwater resources. ASR uses this extant infrastructure to instead actively inject treated water into deep aquifers. The high energy demand of ASR technology may complicate its role as a climate adaptation strategy, because the generation of electricity used in ASR can itself contribute to climate change. In the Pacific Northwest, readily available low-cost hydropower from Columbia River dams, a relatively low-carbon energy source, lends to the increasing implementation of ASR technologies. The existence of traditional big infrastructure is therefore essential to the ongoing regional development of ASR technology by providing the necessary foundation for both water and energy resources (Gleick, 1994).

Similar to conventional infrastructure such as interbasin transfers and dams, ASR is capable of temporally and spatially displacing water for optimal use by humans. Unlike most conventional infrastructure, however, purported environmental benefits are integrated into the motivations for ASR projects. Frequently cited environmental advantages of ASR include more efficient storage resulting from less evaporative loss, improved water quality through filtration by unconsolidated aquifer materials, and the potential for augmenting river baseflows through surface water-groundwater exchanges (Dillon et al., 2006). Because of its potential to use recycled water to passively recharge aquifers and thereby provide fit-for-purpose water for non-potable uses such as irrigation, ASR can, in some cases, be considered a hybrid between supply- and demand-side approaches (Toze, 2006). The development of ASR as a major water-management strategy in developed countries therefore emerges from the context of environmental regulation, including laws related to water quality, environmental instream flows, and endangered species. Nevertheless, despite its purported minimal on-site impacts, ASR can be associated with direct environmental impacts such as dredging, scraping, erection of barriers, and other strategies to enhance recharge (Dillon, 2005). The major limitation of ASR as an environmentally benign management response to climate change and water scarcity is its reliance on specific geographic contexts for its successful and cost-effective application, such as favourable geology (large aquifer storage capacity, unconsolidated aquifer materials for filtering and passive recharge), existing water infrastructure (groundwater pumps and distribution canals), and low-cost electricity (for the energy required for pumping groundwater and active injection into deep wells).

CONCLUSIONS

The Merced and Umatilla projects are both examples of an emerging trend in water management, particularly in developed countries, toward auxiliary water-storage infrastructure that does not involve the construction of new dams but instead leverages existing infrastructure to increase storage capacity. The development of these types of projects is driven by the desire of water managers to adapt to climate change through supply-side infrastructure projects that are consistent with management culture while also creating the smallest possible spatial and environmental footprint. Auxiliary infrastructure projects are attractive to water managers because they purportedly work within the modern framework of environmental regulation that often precludes the development of new large dams in developed countries. Although the two case studies show some similarities in their approach to increasing water storage, they differ in their physical and institutional contexts and have complex interactions with the regulatory environment. The Lake McClure Expansion Plan risks setting a precedent that could allow Wild and Scenic River protections to be thwarted by development projects. In the case of the Umatilla Basin Aquifer Recharge Project, part of the stated motivation for the project is to benefit salmon species that are protected under the Endangered Species Act. The nature of the project is constrained by water-quality laws that require actively recharged water to meet drinking water-quality standards, which necessitates the passive recharge scheme adopted by the project. Understanding how auxiliary infrastructural projects both influence and are influenced by environmental regulations is critically important because, with growing concern about increasing water demand and decreasing supply, such projects are likely to become increasingly common.

One of the nominal advantages of these auxiliary water-storage projects is that, compared to construction of new dams, they require little additional land for the purpose of storing water. At the time that the amount of water stored in artificial reservoirs was increasing as a result of dam construction, the amount of water stored in natural bodies was decreasing, such as in aquifers (because of groundwater withdrawals) and in floodplains and wetlands (as a result of urban development, channelisation, and drainage) (Gibbs, 2000). One of the advantages of ASR is that it restores the natural storage potential of aquifers. Nevertheless, it has serious disadvantages as well, such as intensive energy use, the need to protect aquifer water quality from potentially contaminated recharge water, the possibility of clogged aquifer pore spaces from excessive sediment concentrations, and the potential need for land modification to enhance recharge (Bloetscher et al., 2014). As an alternative water-storage strategy, river restoration projects that increase the storage capacity of floodplains and wetlands have the potential to significantly enhance climate-change resilience by storing excess water during wet periods and releasing it during dry periods (Palmer et al., 2009). This type of proactive adaptation also benefits the ecological and aesthetic quality of river systems.

In addition to auxiliary storage infrastructure, other technologies for expanding water supply are being developed. With increasing scarcity of traditional surface water and groundwater supplies and improvements in technology, non-traditional projects such as wastewater recycling and desalination are more common (Jefferson et al., 2000; Karagiannis and Soldatos, 2008). Similar to auxiliary storage infrastructure, these alternative supply technologies are centralised supply-side solutions that depend on existing energy infrastructure (McEvoy and Wilder, 2012; Ormerod and Scott, 2012). In contrast, spatially-distributed water-collection strategies such as rainwater harvesting provide a different approach to water-supply augmentation that can be carried out at the scale of individual households (Pandey et al., 2003; Meehan, 2012). Rainwater harvesting, however, does not necessarily provide a reliable year-round supply of water and poses potential issues for regional water balance if implemented at a large scale, so it can be considered a supplementary supply at best (Ngigi, 2003). Water reclaimed from alternative supplies can be potentially stored in aquifers as part of an ASR project in order to reduce evaporative losses, improve water quality, and contribute to river baseflow, although with the negative impacts of ASR projects (Miller, 2006). These alternative supplies and auxiliary storage infrastructure such as ASR can potentially reinforce one another to create new integrated systems of water resources in which both the water source and the storage mechanism are artificial.

While augmenting the height of a dam requires nominal energy inputs, there is a trade-off between water supply and flood protection. For example, capturing more water for storage behind a closed flood gate in turn shifts the balance in favour of supply at the expense of downstream flood mitigation. Both storage infrastructure and alternative supplies are limited in their focus on supply-side management. Clearly, there is substantial potential for further adaptive capacity in demand-side measures such as water conservation, efficiency, switching to less water-intensive crops (Dawadi and Ahmad, 2013), the local food movement, and reducing food waste (Martinez et al., 2010). Lining and covering canals and blanketing reservoirs can reduce seepage and evaporative losses (Gallego-Elvira et al., 2011). Water conservation is an example of a no-regrets strategy, which will have economic and environmental benefits regardless of the nature and extent of future climate change (Frederick et al., 1997). Such robust adaptation strategies are essential for comprehensive management of water resources in a changing climate. Auxiliary water-storage infrastructural projects, however, can potentially create perverse disincentives for water conservation by creating a perception of abundant supply.

Auxiliary water infrastructure represents a continuation of the same high-modernist water management practices that led to large reclamation projects in the U.S. West over the 20th century. Although auxiliary infrastructural projects have a smaller land footprint and are more constrained by modern environmental regulations compared to the construction of wholly new infrastructure, they are still limited to a supply-side, centralised outlook on water management. In order to fully address the challenges presented by climate change and the interrelated issues of population growth and economic development, the water-management strategies of the 21st century need to be radically different from those of the 20th century. An approach to water management that comprehensively addresses both supply and demand using both infrastructural and institutional strategies would be truly transformative and would provide the highest level of protection of water resources in a changing climate. Given the uncertainty of future water supply, increasing water storage alone is likely to be insufficient, which necessitates demand-side strategies that make the best possible use of the available water supply.

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