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Hydrodiplomacy and adaptive governance at the U.S.-Mexico border: 75 years of tradition and innovation in transboundary water management

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ABSTRACT

The United States and Mexico have engaged in hydrodiplomacy—a practice of transboundary water management that blends water diplomacy and science diplomacy–for more than 75 years, since the adoption of the Treaty of 1944 and the creation of the International Boundary and Water Commission. We examine six major turning points in U.S.-Mexico hydrodiplomacy to ascertain the key factors in the region's history of resolving transboundary water issues. We find that recognized adaptive governance indicators—such as social learning, sustained relationships, flexible governance mechanisms, and state and non-state networks are essential elements of hydrodiplomacy. Our research suggests that robust and foundational institutions comprise another key indicator of adaptive governance specifically in transboundary contexts. A commitment to both science and diplomacy have been important components underlying the effectiveness of hydrodiplomacy in the border region. Binational networks involving diverse state and non-state actors at multiple scales have increasingly played a pivotal role in shaping desirable hydrodiplomatic outcomes in the region.

1. Introduction

For three-quarters of a century, the United States (U.S.) and Mexico have utilized science and diplomacy to manage their shared water resources. In 2019, the two countries achieved a significant milestone, the 75th anniversary of the adoption of the Treaty of 1944, which allocated the waters of the Rio Grande (Río Bravo in Mexico), the Colorado River, and the Tijuana River between the two countries. The year 2019 also marked the 25th anniversary of the environmental agreements associated with the North American Free Trade Agreement (NAFTA).[1] Despite increasing socioeconomic and institutional complexity and uncertainty over the effects of climate and environmental change, the binational relationship around transboundary water resources has grown more resourceful. That relationship confronts increased complexity and uncertainty by employing adaptive management in water governance to achieve shared objectives.

Although wealth and power asymmetries characterize their relations, the U.S. and Mexico have successfully navigated a path by generally—albeit not exclusively—moving away from conflict and toward cooperation and even collaboration (Wilder et al., 2019). This article examines U.S.-Mexico hydrodiplomacy through the lens of adaptive governance practiced at different scales to assess how transboundary water management has coped with the intricacies of regional complexity and uncertainty.

2. Theoretical approaches

2.1. Hydrodiplomacy

Hydrodiplomacy draws together two conceptual frameworks—*water*

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[1] A revised version of NAFTA, the U.S.-Mexico-Canada Agreement was approved on December 19, 2019, by the U.S. House of Representatives, by the U.S. Senate on January 16, 2020, and by the U.S. president on January 20, 2020. By early April, the agreement had been signed and ratified by Canada and Mexico, as well.

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diplomacy and *science diplomacy*—to define the ways countries work together to resolve water-resources problems at their shared borders. Water diplomacy, as defined by Islam and Susskind (2013: 323) is a "theory and practice of adaptive water management" whereby countries use flexible, non-zero-sum approaches and adaptive governance strategies (e.g. actor networks, capacity-building, social learning[2]) to address cross-border water issues. They argue that working from the traditional silos of science and policymaking is insufficient to address the complexity of water resources systems affected by population growth, economic development, and climate change. According to this view, sustainable solutions can only emerge from "diplomacy that takes science, policy, and politics into account" (Islam and Susskind, 2013: 323). *Diplomacy* refers to interactions between countries that explicitly seek to avoid hostility and conflict. For this reason, Islam and Susskind (2013: 323) utilize "specialized techniques" that focus on very specific issues (such as water allocation) while embracing diverse stakeholder interests. Practitioners of water diplomacy seek not just to resolve a particular issue, but to build capacity via social learning among the diverse network of stakeholders involved in a particular water resources issue. Water diplomacy yielded positive results in, for example, a multistakeholder process to mediate the conflicting interests of environmentalists and the sugar industry in the Florida Everglades by involving cooperation across different government scales (Islam et al., 2013: 225–232) and in strategic adaptive management in South Africa's Kruger National Park, which is a downstream user of six rivers involving combinations of four countries (Islam et al., 2013: 239–250).

Science diplomacy has been defined as "the use of science to prevent conflicts and crises, underpin policymaking, and improve international relations in conflict areas where. . . science can open new channels of communication and build trust" (European Commission, 2016: np). For example, in the postwar international order, scientists and diplomats of multiple countries worked together to achieve shared international objectives, such as Cold-War information exchange among Soviet and Western scientists to limit nuclear arms proliferation, control infectious diseases and protect marine environments; and establish centers of scientific excellence in Africa, the Middle East, and southeast Asia (Colglazier, 2018). The 1965 – 74 International Hydrological Decade, 1987 Montreal Protocol to protect the Earth's ozone layer, 2015 Paris Climate Accord, and 2015 U.N. Sustainable Development Goals are examples of broad international scientific and political collaboration involving science diplomacy.

These frameworks have in common an emphasis on non-conflictual, flexible approaches informed by knowledge and science. In our use of the term "hydrodiplomacy," we seek to highlight both a strong role for science in diplomatic processes around water and a robust role for formal institutions (e.g., laws, treaties) in shaping water resources negotiations. Hydrodiplomacy involves formal actors, such as the participants in traditional diplomacy, but at the same time it explicitly embraces multiple stakeholders. Thus, it moves away from a vertically-integrated, top-down approach to a more horizontal and inclusive, network-reliant approach.

Hydrodiplomacy concerning transboundary water resources between the U.S. and Mexico took formal shape in 1944 with the treaty and gained significance in the postwar atmosphere of international cooperation and development of institutions and has only become more salient and relevant in recent decades. A 2018 analysis of "future worlds" (*Foreign Affairs,* 2018) suggests that among the various kinds of diplomacy, hydrodiplomacy may be the most consequential form of international scientific and political collaboration. According to Colglazier (2018), transboundary diplomacy over water resources is perhaps the single steepest future challenge. A "warming-world" scenario (*e.g.*, Busby, 2018: np) suggests that climate change "matters more than anything else, and will test the international system in new and unpredictable ways." Colglazier (2018) believes this scenario portends greater international conflicts over water, especially in developing countries.

Effective hydrodiplomacy thus emerges as a critical institutional objective for the 21st century and presents an important question to resolve: *What are the elements of effective scientific and political collaboration around transboundary water?* Susskind and Islam (2012) note that there is no one-to-one correlation between science and better water management. Scientific information has proliferated in the last quarter-century, and yet most global water problems have remained intractable. Most transboundary water conflicts involve allocation, purveying a "zero-sum" view of water as a finite resource, yielding only clear winners and losers; others may involve water quality disputes. Susskind and Islam (2012) argue that avoiding such framing is the most important aspiration for water-resources negotiations. Instead, effective hydrodiplomacy requires stakeholders to see water as a flexible resource, and to build trust that can achieve agreements that promote common interests.[3]

2.2. Adaptive governance of water resources

Adaptive governance of water resources is a vital way to practice hydrodiplomacy. Adaptive governance helps create and maintain the essential building blocks that aid hydrodiplomacy, such as science policy and state/non-state networks, sustained and iterative relationships, and social learning (Fig. 1). Adaptive governance can be seen as an iterative and dynamic approach that responds to conditions of uncertainty and complexity (Chaffin et al., 2014). Sometimes known as "adaptive management—or "adaptive (co)-management" (Huitema et al., 2009; Folke et al., 2005)—adaptive governance eschews static water-resources management prescriptions, opting instead for engagement and knowledge exchange with diverse stakeholders, usually loosely, or formally organized within a multiscalar network (Cash et al., 2003). Adaptive governance incorporates uncertainty in the decision-making, allowing learning by implementing and testing out management actions in an iterative cycle (Varady et al., 2016). And, for use in hydrodiplomacy, it is a congenial approach for handling transboundary water and climate issues (Varady et al., 2013).

Adaptive governance integrates scientific knowledge with local knowledge, making scale an important dimension in the management and policymaking process. The term "governance" is at once the "ways organizations are managed and the systems for doing this" (Cambridge English Dictionary). It refers to the formal and informal actors and institutions that make decisions about water use and allocation and management at different scales—including potentially, international, national, state, local, community (*e.g.*, such as communal farmers or foresters), and household scales (Lemos and Agrawal, 2006; Conca, 2006). Adaptive governance processes recognize that water resources

[2] "Social learning" refers to learning that takes place within groups of water decision makers and water users ("actors") working in formal or informal networks over a sustained period of time to resolve issues. Social learning can mean the development of common knowledges and vocabularies, the ability to reframe problems or understand problems within a different context, among the actors in a given network (Pahl Wostl et al., 2007). Examples of such groups are river basin councils (Pahl Wostl et al., 2007) or science-policy stakeholder groups (Gerlak, 2015).

[3] The concept of hydrodiplomacy is related to other frameworks that theorize how countries relate around water, including, "hydrohegemony" which Zeitoun and Warner (2006) define as "hegemony at the river basin level, achieved through water resource control strategies such as resource capture, integration and containment." At the other end of the spectrum from hydrohegemony is "hydrosolidarity." Falkenmark (1999) defines it as having three characteristics: (1) human water obligations are human rights; (2) upstream/downstream relations should prioritize sharing of water; and (3) ethical, religious, and philosophical considerations should inform water ethics. An article relating these frameworks with hydrodiplomacy is planned.

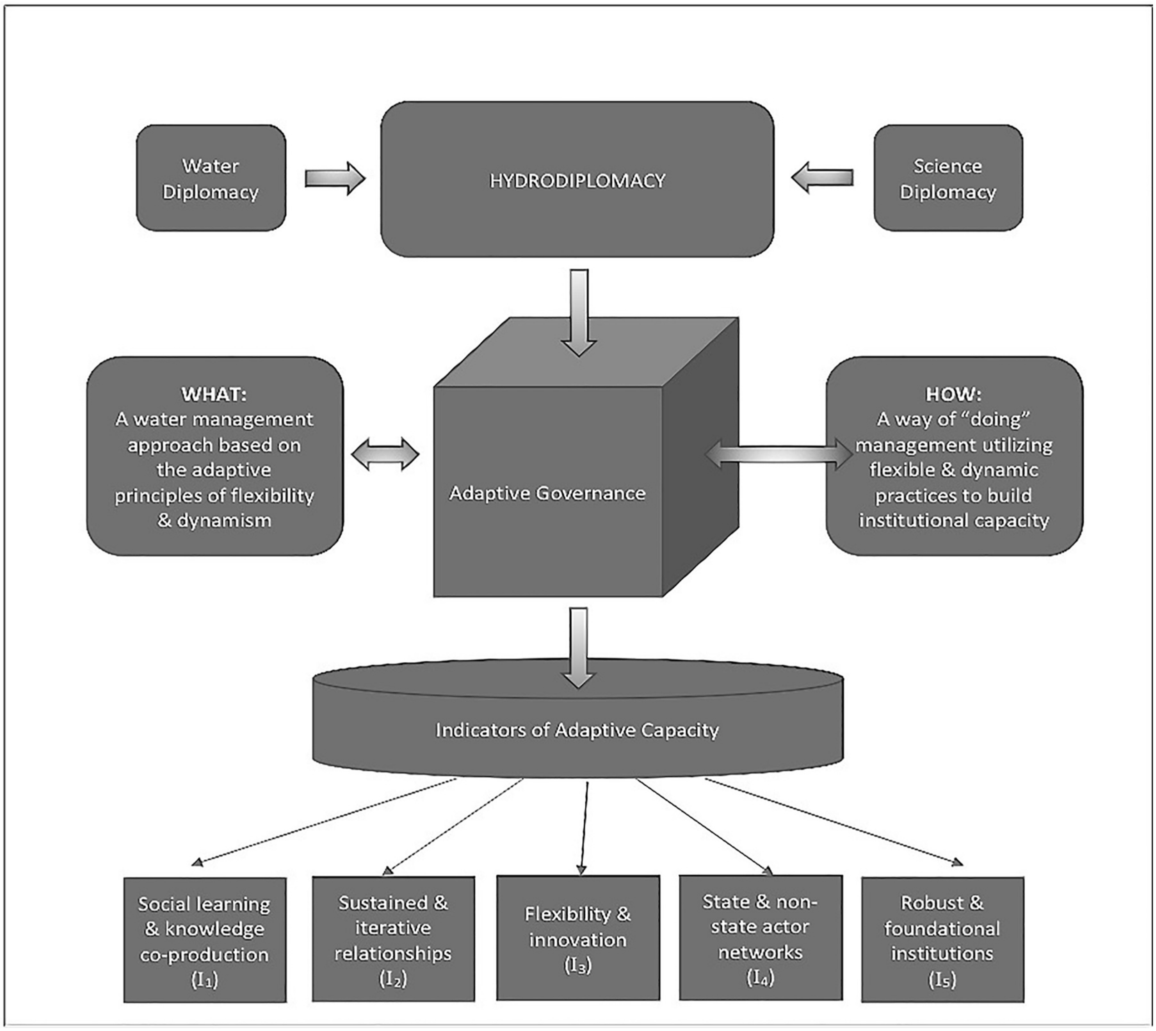

Fig. 1. Conceptual framework for hydrodiplomacy and adaptive governance.
Hydrodiplomacy refers to a type of water governance in complex transboundary social-ecological systems. It combines both water diplomacy and science diplomacy frameworks. Governance is a multidimensional concept that is at once "the ways organizations are managed and the systems for doing this" (*Cambridge English Dictionary*). Adaptive governance (AG) is a water management approach based on the *principles* of flexibility and dynamism. It is also a set of *practices*—or a way of doing—water management with a goal of building institutional capacity. Studies of effective AG provide evidence that specific characteristics (indicators, I) of governance arrangements have been identified that contribute to institutional adaptive capacity. Our work suggests that a 5th indicator, robust and foundational institutions (e.g., Treaty of 1944; IBWC/CILA) is key to adaptive governance in a transboundary context
(Source: M. Wilder).

issues can be at once international, national, state, and/or local in terms of their importance and impacts. Hydrodiplomacy that utilizes adaptive governance processes thus involves scalar dynamics that often may be state-to-state, but could also be state-to-local, local-to-local, and/or involve specific communities (*e.g.*, farmers, fishers or foresters) and may centrally involve expert communities such as scientists and government/policy professionals in broad networks (Chaffin et al., 2014; Pelling et al., 2008; Lemos and Morehouse, 2005).

Adaptive governance of social-ecological systems relies on the social institutions involved in use of and decision-making about resources as well as the social networks that form in the process (Folke et al., 2005). The adaptive capacity of the institutions and networks is key to the success or failure of adaptive governance processes (Folke et al., 2005; Gupta et al., 2010). Key components of adaptive governance include: social learning (Pahl-Wostl et al., 2007; Pahl-Wostl, 2009); diverse networks of state and non-state actors and institutions (Folke et al., 2005; Lejano et al., 2013); sustained and iterative relationships (Lemos and Morehouse, 2005; and flexibility and innovation (Folke et al., 2005).

Social learning (Berkes, 2017; Islam et al., 2013; Pahl-Wostl, 2007; Pelling et al., 2008) within the science-stakeholder institutions involved in water-resources management also contributes significantly to adaptive governance. Learning may develop or be fostered through individuals or groups, but also via external, formal governance processes (Heikkila and Gerlak, 2013). Sustained interactions of this type contribute to building trust among disparate interests (Lemos and Morehouse, 2005).

Transboundary social learning develops shared definitions and conceptual understandings of issues such as climate change impacts or regional vulnerability and resilience, thereby co-producing new knowledge shared by both countries (Lemos and Morehouse, 2005). Through social learning, stakeholder networks of state and non-state actors may help introduce and foster new institutional priorities, policies, and practices within and among water-management institutions (Wilder et al., 2010). Such networks—in durable relationships with each other—practice learning and experimentation and may innovate solutions to complex problems (Gerlak, 2015). Adaptive-governance systems commonly integrate local knowledge with scientific

Fig. 2. U.S.-Mexico border, border states, and selected rivers.
(Source: Adapted by the authors from IBWC, n.d.)

knowledge, exhibit strong leadership, and accept change and uncertainty (Folke et al., 2005). Actors can take advantage of disruptions (e.g., new policies, funding opportunities, or even natural disasters) to help shift toward adaptive governance (Olsson et al., 2006).

3. U.S.-Mexico border region: Background and context

The 3218-km (1956-mile) boundary between the two nations defines a borderlands region. This strip comprises parts of 10 states (California, Arizona, New Mexico, and Texas in the U.S.; Baja California, Sonora, Chihuahua, Coahuila, Nuevo León, and Tamaulipas in Mexico) (Fig. 2).

The border area is arid-to-semiarid, and its rugged, yet fragile landscape exhibits a biodiversity that is among North America's highest. It features varied wildlife (including endangered species) and vegetation in ecological zones ranging from coastal plains to deserts, including protected areas.[4] Some dozen transboundary rivers lie within the region, including two major ones: the Rio Grande (Río Bravo in Mexico), which defines the Texas-Mexico border; and the Colorado River, which demarcates a 38 km (24 miles) portion of border known as the limitrophe and then crosses into Mexico. More than 20 transboundary aquifers underlie the border, further linking the two countries' hydrological systems (Albrecht et al., 2018). Climate-change projections indicate rising temperatures and longer, more severe droughts by mid-century, impacting water supply (Garfin et al., 2013).

Since the 1950s, the bilateral border relationship has become more complicated. The organic interdependence of two distinct countries—owing to their geographic proximity and shared history—is key to understanding their relationship. Their economies, cultures, and political systems are disparate, leading to cycles of conflict and accommodation over immigration, labor, trade, disaster management, narco-trafficking control, and sometimes, water (Liverman et al., 1999; Wilder et al., 2019).

The population within the border strip is about 14 million people, residing primarily in paired border cities, including San Diego/Tijuana (4.9 million population), and El Paso/Ciudad Juárez (2.2 million), with smaller cross-border towns and multiple rural settlements (Ganster and Lorey, 2016: 3). Major economic drivers include *maquiladoras* (foreign-owned assembly plants), copper mining, irrigated agriculture, ranching, and increasingly, recreation and tourism.

Poverty and economic asymmetry characterize the area, where an advanced industrialized economy borders a developing economy. In places, average incomes in the U.S. can be as much as ten times greater than in Mexico. Yet regional asymmetries persist within each country as well as across the border. The U.S. border counties (with the exception of San Diego County) remain among the poorest in the nation. In contrast, Mexico's north and northwest enjoy a higher GDP than the country as a whole. In the U.S., sunbelt-oriented migration has caused the spread of housing subdivisions and commercial sprawl, while in Mexico informal *colonias* (unplanned residential developments) that often lack basic services (water and sanitation hookups, electricity, and paving) characterize border towns.

Given uneven development and contentious relationships around immigration and drug-enforcement policies, it is remarkable that hydrodiplomacy generally has been effective. Wilder et al. (2019) argued that the U.S. and Mexico have, in general, moved away from transboundary-water conflict and toward cooperation and collaboration, though the conditions and relationship are dynamic and continually changing.

In section 4, we analyze turning points in hydrodiplomacy in the region as reflective of an adaptive water governance approach. In the final section, we identify distinctive adaptive-governance indicators that help explain the relative effectiveness of hydrodiplomacy at this border and assess any implications for other global regions. We consider hydrodiplomacy to be "effective" when, in cases of discord, the conflict is resolved by agreement rather than by litigation (or violence) and when the two countries are able to move beyond the conflict. In other cases, hydrodiplomacy is effective when innovative arrangements achieve goals that both nations have defined in collaboration with one another.

4. Turning points in U.S.-Mexico hydrodiplomacy

To illustrate this shifting relationship, we offer six studies (Fig. 3) of turning points in this region's hydrodiplomatic relations—using the framing of adaptive governance as a lens into the workings of hydrodiplomacy—focusing on social learning, trust-building via sustained relationships, flexibility and innovation in governance, and

[4] Notable protected areas include: the Tijuana Estuary, Organ Pipe Cactus National Monument (adjacent with Pinacate Biosphere Reserve in Mexico), the San Pedro Riparian National Conservation Area, and Big Bend National Park.

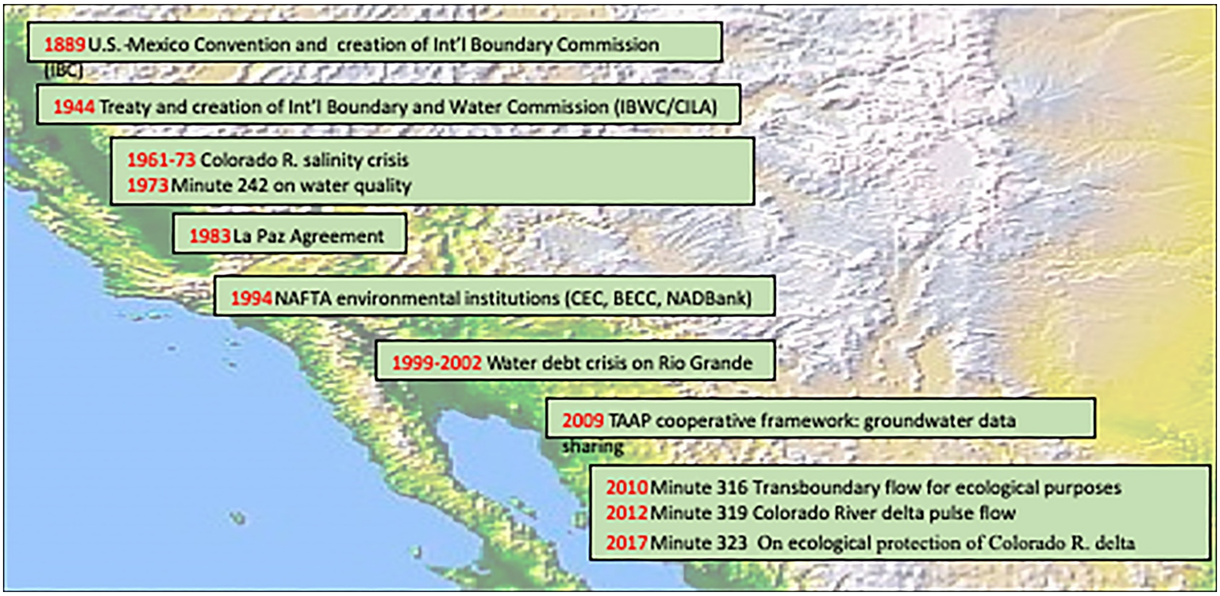

Fig. 3. Timeline of U.S.-Mexico hydrodiplomacy turning points (prepared by R. Varady).

involvement of networks of state and non-state stakeholders. Our own research suggests a fifth indicator is significant for transboundary adaptive governance: the presence of strong, foundational institutions (see Fig.1). In each case, we examine what these characteristics tell us about the role of science and diplomacy.

4.1. The 1944 treaty and IBWC/CILA

The 1944 Treaty[5] was and remains one of the signature 20th century-agreements reached between Mexico and the U.S. The accord, struck at the height of World War II, when the U.S. sought to deepen its ties with Mexico and Latin America, is exceptional for its technical complexity and institutional design and, 75 years later, for its durability—all of which contribute to its proven adaptive capacity.

The treaty's hydrological complexity derives from the fact that it addresses the transboundary allocation and management of water on the three most important shared rivers. The Rio Grande, forms the international boundary for 1930 km (1200 mi); the Colorado, is the boundary for 38 km (24 mi); and the Tijuana, links the most urbanized, far-western section of the boundary. These rivers and their tributaries serve a binational population in excess of 70 million people.

The treaty considers each river separately in matters of allocation, infrastructure and development, and shortage:

1. Rio Grande: Article 4, grants the U.S. 350,000 acre-feet (af) (431 million m^3) of water annually averaged over a five-year cycle. It also authorizes construction of dams and hydropower facilities and sets a formula for managing shortage under extraordinary drought.[6]
2. Colorado River: Mexico is allocated 1.5 million af (1850 million m^3) of water annually, authorizes construction of a major diversion dam channeling water to Mexico, and provides for proportional reductions in allocation under extraordinary drought shortage conditions.
3. Tijuana River: Allocation and development were postponed, with a framework allowing future negotiations on river management as needed. Flood control works and sanitation facilities have since been developed.

Not only does the treaty address water management on these major rivers, it also considers binational sanitation problems, envisions negotiation of future joint water projects, and enfolds boundary treaties and management under its administrative umbrella. This functional intricacy enhances the treaty's importance and legitimacy, engaging a wide and diverse range of stakeholders in its operations (Mumme, 2019).

The treaty's institutional design contributes to its adaptive capacity and resilience in the face of emerging challenges. Its joint administrative mechanism is the International Boundary and Water Commission (IBWC) and its Mexico counterpart, CILA (Comisión Nacional de Límites y Aguas). This binational institution is composed of two separate, politically distinct national sections (IBWC/CILA, hereafter IBWC, unless the Mexican unit is being specified). Each section is under the oversight of its national foreign ministry, and is empowered to: (1) interpret and apply the treaty's provisions with the assistance of domestic agencies, (2) monitor and investigate potential problems, and (3) resolve any disputes through negotiation and, if necessary, international dispute settlement mechanisms (Treaty between the United States of America and Mexico, 1944a).

The treaty permits crafting subsidiary agreements, known as "minutes" (or technical amendments), implementing and applying their provisions to problems—water, sanitation, or boundary-related—as the commissioners deem necessary (Treaty between the United States of America and Mexico, 1944b). More than 145 such minutes have been signed since 1945, addressing a spectrum of implementation issues. This "minute process" allows the governments to extend the treaty's reach to matters not originally envisioned, to include water quality, groundwater, transboundary watercourses unmentioned in the Treaty, and more recently: conservation and innovations in managing shortage; environmental protection; and ecological restoration. The treaty thus functions flexibly and dynamically, encouraging stakeholders in both countries to work within its architecture to resolve disputes and address emerging challenges.

The 1944 Water Treaty today provides the foundation and framework for binational engagement across the range of water and boundary problems in the U.S.-Mexico border region (Mumme, 2019). Its complexity insulates it from political challenge, even when serious disputes arise. The treaty, in effect, compartmentalizes such problems and encourages the neighbors to cooperate, knowing that stakeholder

[5] Officially, the Treaty on Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande.

[6] The formula allows water debt to be rolled to the following five-year cycle and cancelled entirely should precipitation fill the Rio Grande River's two major storage dams, Amistad and Falcon, to capacity.

concerns in one treaty domain are not necessarily transitive to another. In this aspect the treaty has benefited from the diverse hydrologies and domestic political configurations as well as from its application to the long international boundary. In addition, the treaty's record of problem resolution reinforces its legitimacy at the national governmental level and among the various subsidiary jurisdictions and stakeholders invested in its institutional success. Its effective implementation requires strong scientific and technical input and leadership; the commissioners are required to be engineers and the minutes are developed using state-of-the art hydrological modeling and other scientific tools. In addition, in developing and implementing minutes, the IBWC operates iteratively. These arrangements highlight the presence of the adaptive capacity indicators based on a strong role for science and sustained, iterative relationships.

Going forward, it is vital to protect and shield the treaty's institutional joint mechanism, IBWC, from national and binational geopolitics. Potential threats include rhetorical antagonisms by populist politicians, tariffs and trade disputes, immigration, and narcotrafficking. The treaty instrument's community of practice needs to be augmented via greater local engagement on water issues—particularly through citizen fora in Mexico, where water is managed by experts and where administration remains very centralized. Fortunately, binational water management has experienced appreciable social learning at all levels—most evidently on the U.S. side, but also in Mexico through increased academic-sector participation.

4.2. The salinity crisis (1961–1973)

The 1961–1973 Colorado River salinity crisis tested and eventually consolidated binational support for the treaty (Mumme, 2017). As such, it remains a constitutive element of the treaty as practiced today, effectively adding a commitment to sustaining water quality to the agreement's mandate. The Salinity Crisis is a salient example of two divergent sides developing shared perspectives through learning over time, ultimately finding a way forward together.

The dispute over the salinity of Mexico's treaty water arose when the U.S., without prior notice, began disposing high-saline drainage water to the Colorado from an irrigation district just north of Yuma, Arizona. The saline level of Mexico's treaty water at the international boundary spiked abruptly, threatening agriculture in Baja California's Mexicali Valley. Mexico's urgent protest was rejected by the U.S. which pointed to Articles 10 and 11, obligating Mexico to accept Colorado treaty water from "any and all sources" and "whatever its origin."

The 1944 Treaty failed to explicitly address the water-quality question, an intentional oversight by its formulators.[7] The dispute thus juxtaposed two fundamentally opposed legal readings of the treaty. One, favored by the U.S., adopted a strict interpretation of the articles stipulating each nation's obligations. The other, favored by Mexico, looked to the treaty's overarching purpose as a rule for acceptable water quality. Mexico also claimed its irrigators were entitled to the same level of water quality enjoyed by U.S. water users in the Imperial and Yuma Valleys just north of the border (Mumme, 2017).

As key stakeholders, the seven U.S. basin states implacably opposed any concessions to Mexico, arguing Mexico's treaty water was usable for some purposes and that salinity was a naturally-occurring basinwide problem, therefore a shared burden. By 1964, however, U.S. State Department diplomats realized that this position was untenable in international law and urged resistant basin states to adopt a negotiating approach based on "reasonableness," not "usability." An interim agreement, IBWC Minute 218, signed in 1965, allowed Mexico to channel the saline drainage-water through a U.S. financed canal, with the unused water charged against its treaty allotment. In the meantime, Mexican farmers stepped up groundwater use along the boundary and intensified their protests of U.S. action.

Developments in international law—particularly adoption of the 1966 Helsinki Accords' principle of "equitable and reasonable utilization" of international watercourses—weakened the U.S. negotiating position as negotiations resumed in 1970. Mexico's new president, Luís Echeverría, made the issue a top priority, threatening to take the matter to an international tribunal. U.S President Richard Nixon, who saw the issue as a complication for strengthening hemispheric relations, was determined to settle the matter, assigning former U.S. Attorney General, Herbert Brownell, as his special ambassador to Mexico for that purpose. Brownell successfully convinced reticent U.S. states to accept a commitment to salinity control. The states' concession was predicated on federal construction of a desalination facility to purify drainage water released to Mexico and federal support for a long-term, basinwide salinity-control program. IBWC Minute 242, ending the dispute, was signed in August 1973.

While never actually abandoning its legal position, the U.S. concession effectively conforms to the Helsinki doctrine of reasonableness favored by U.S. diplomats. Under Minute 242, the U.S. is obligated to sustain water quality at the international boundary at a level +/- 115 ppm (ppm), the salinity level at Imperial Dam, the major diversion dam for the U.S. lower Colorado River region. The U.S. did not accept liability for damages to the Mexicali Valley, but did provide limited rehabilitation assistance. The two countries pledged to control groundwater extraction below Yuma on the Arizona-Sonora boundary[8] and (eventually) pursue a groundwater treaty, effectively drawing groundwater under the treaty's purview.

The protracted negotiations reveal a path of iterated policy learning by both countries. This process played out in a dynamic political arena informed by domestic water law and by practice. This course of action included developments in the emerging international law of transboundary watercourses, and the regional and global strategic ambitions of Mexican and U.S. administrations. It also reveals the value of the treaty, whose design proved sufficiently flexible to allow a diplomatic solution to a vexing problem that threatened to derail bilateral support for its measures. Instead, the treaty was actually strengthened by commitments to water quality, aided by scientific data and assessment, and groundwater that benefit subsequent agreements.

4.3. NAFTA and its U.S.-Mexico environmental institution: BECC/NADBank (1994-present)

The agreement to create two institutions to address environmental protections as part of the North American Free Trade Agreement (NAFTA) exemplified a growing role for non-state actors and an expanded adaptive capacity for institutional arrangements to address environmental issues, particularly in the U.S.-Mexico border region.

Trade between Mexico and its giant neighbor to the north has mirrored political relations. At the turn of the 19th century, as a proud exertion of his nation's independence, Mexican authoritarian president of three decades, Porfirio Díaz resisted increasing cross-border trade. "Between the United States and Mexico," he allegedly said, "we want

[7] The Treaty drafters dodged this issue by providing sufficient ambiguity to allow each country to have its own construal of how the agreement applied. Water quality is explicitly referenced in Articles 10 and 11 for the Colorado River which gave the U.S. confidence the question was covered. It was not mentioned anywhere else (if sanitation is discounted). Mexico was content with this in the sense they viewed the Colorado River language as subordinate to the broader aims and purposes of the Treaty set out in the Preamble, and articles 1 and 2 of the Treaty (Hundley, 1966; Enríquez Coyro, 1976).

[8] The regulatory pumping zone authorized in Minute 242 is located only on the Arizona-Sonora boundary along a 21km-long (13-mile) strip that straddles the southerly international boundary that runs east from the San Luis Río Colorado (see the USBR page: https://www.usbr.gov/projects/index.php?id=376).

Fig. 4. Map of the Colorado River basin and delta.
Source: Carter et al., 2018. Based on The Earth Institute at Columbia University, at http://blogs.ei.columbia.edu/wp-content/uploads/2012/12/CO-River-Basin-REVISED.jpg; modified by CRS. Note that the Gulf of California (shown here) is also known as the Sea of Cortez.

not the sound of the locomotive, but the sound of the desert" (Orme, 1996).

Notwithstanding those protestations, in the post-World War II period Mexico's trade began relying increasingly on the U.S.—with interspersed periods of growth and retrenchment. In Mexico's north, the maquiladora program that promoted development of foreign-owned assembly plants in the border region began in 1965, spurring a take-off in trade and commerce from the early 1980s onward. The number of maquiladoras—80 percent of them in the border region—grew from around 500 in 1975 to 1300 in 1993 before surging in the immediate post-NAFTA period to 2700 at their peak (Anderson and Gerber, 1999: Figure 4.1, p. 91), a growth accompanied by a commensurate rise in bilateral trade Fig. 4.

However, before 1993, recognition of the link between trade and environment remained negligible. There was trade. . . and there was environment. But when the two nations began considering a free-trade agreement, environmental groups perceived the potential for harm to the mostly arid border environment and its natural resources. These groups envisioned a major increase in truck traffic; growth in population (already evident in the magnetic effect of maquiladoras, whose employees grew sixfold from 1983 to 1993); the attendant resource requirements; the hazards posed by cross-border toxics, pollution, and discharges; and perhaps most of all, the insufficiency of infrastructure to support further growth.

Thus, when in the first years of the 1990s Mexico and the U.S. entered into serious negotiations for what became the trinational (Canada, U.S., and Mexico) NAFTA, national and local environmental nongovernmental organizations raised concerns. Binational accords on some transboundary environmental issues were already an established feature (e.g., the 1944 Treaty) and a robust institution, IBWC, had been created to deal with matters regarding transborder water. As well, in 1983 the two neighbors negotiated an environmental accord known as the La Paz Treaty (Córdova and de la Parra, 2009) that addressed not only water, but air quality, pollution, hazardous materials, and land use. So, when NAFTA negotiations neared completion, environmentalists—who were otherwise unfavorably disposed to the accord—cited the existing institutions and flexed their collective muscle[9] to convince the three national administrations to consider adding institutional provisions safeguarding the environment, particularly the water-short and fragile U.S.-Mexico border region (Mumme, 1993).[10]

After four years of negotiations, NAFTA became law on January 1, 1994. The agreement created what was then the world's largest free-trade zone, with objectives to “remove tariffs and nontariff barriers; enhance fair competition; promote investment; protect intellectual-property rights; institute practical procedures for resolving disputes; and facilitate trilateral, regional, and multilateral cooperation” (Varady, 2007: np). With NAFTA in place, the rise in maquiladoras increased exponentially and population growth intensified in Mexican border cities. This impact on one side of the border affected the other side.

The agreement established three new environmental institutions: the trinational Commission for Environmental Cooperation (CEC), the product of a side agreement amending NAFTA[11] ; and two binationally-negotiated institutions, the Border Environment Cooperation Commission (BECC; based in Ciudad Juárez. Mexico) and the North American Development Bank (NADBank; based in San Antonio, Texas, U.S.), agreed to by the U.S. and Mexico. By design, both BECC and NADBank had binational boards. Once in place, through CEC, NAFTA became arguably the world’s first major “green” trade treaty, at least in aspiration.

BECC was designed to put in place much-needed environmental infrastructure within the border area (originally defined by NAFTA as a strip 100 km wide on each side of the border and later widened on the Mexican side). Beginning in early 1994, BECC solicited and vetted proposals for projects such as water- and effluent-treatment plants. The commission imposed a set of recognizably progressive criteria for technical feasibility, environmental and financial sustainability, openness, and public participation, which if met would lead to approval. Once approved, proposals were forwarded to NADBank, which either directly provided or sought low-interest loans. This procedure, with some adjustments along the way, remained in place between 1994 and 2017 and led to the approval of dozens of projects (e.g., potable and wastewater treatment plants; air quality improvement, and more recently, green infrastructure) benefiting border communities.

In 2017, BECC was merged with NADBank (Hendricks, 2017). Over its 25-year lifetime, NAFTA has contributed to a sixfold increase in trade. During that same period, more than 250 BECC-NADBank environmental-infrastructure projects (slightly more than half of them in Mexico) have been supported at a total value of some $13 billion (of which $3.1 billion was provided by NADBank, the rest leveraged; NADBank, 2019).

The NAFTA negotiations demonstrated and produced new environmental muscle and capacity, especially important for the U.S.-Mexico border region (see also Gladstone and Liverman article in this volume). Billions of dollars of infrastructure improvements have improved environmental quality within the region since the new institutions were created, incorporating new standards of local participation. In keeping with the adaptive governance principles we outlined above, these institutional arrangements have remained flexible and resilient in the face of potentially disruptive changes in national administration (five in Mexico and three in the U.S.), pulses of political conflict, and chronic funding shortages.

4.4. Water debt crisis on Rio Grande (1999–2002)

The most vexing and persistent problem in U.S.-Mexico water relations has been a 25-year dispute over Mexico’s treaty obligation affecting the middle-and lower reach of the Rio Grande/Río Bravo. This issue arose from a genuine water shortage and from heightened basinwide water consumption. The resolution of the water crisis points to the strength and especially the flexibility of the treaty as the determinative document to help the two countries move beyond the crisis, with an assist from nature.

The 1944 Treaty’s water-sharing contract for the Rio Grande could not be more different from that on Colorado, where the U.S. has a straightforward annual obligation to deliver a fixed amount of water to Mexico. On the Rio Grande, Mexico is required to provide an annual average of 350,000 af (370 million m^3) to Texas in five-year cycles.[12] If Mexico is in arrears at the end of a cycle, it may request forbearance and a debt rollover to the next cycle. Adding to the uncertainty in annual deliveries, Mexico’s water debt is cancelled when the two major storage dams on the boundary-defining portion of the river, Amistad and Falcon, are filled to the brim (Mumme, 2003).

Between 1944 and 1994, Mexico always fulfilled its minimum flow deliveries within the five-year cycles. But due to droughts during the 1994–2003 period, Mexico claimed it was unable to make full deliveries. In the 1980s and 1990s, Mexico had increased irrigated agriculture in both Chihuahua and Tamaulipas states, with demand outstripping supply by the late-1990s in the basin. Consequently, in this drought period, Mexico incurred a water debt during two five-year cycles (Carter et al., 2018).

When Mexico failed to meet its five-year obligation in 1997, the U.S. agreed to carry the debt into a new cycle. But in the summer of 2002, with Mexico still in arrears, a crisis ensued when Mexico failed to deliver minimum required flows to farmers in south Texas. Mexico declared an “extraordinary drought” that, by treaty, allowed it to default on delivering the full minimum allocation to the U.S. Texans were

[9] Six major environmental organizations participated in the development of the environmental side agreements, including National Audubon Society, World Wildlife Fund, and Natural Resources Defense Council. Other major environmental NGOs (including Sierra Club, Friends of the Earth, and Greenpeace) remained opposed to the trade agreement, despite the environmental side agreements (Schneider, 1993).

[10] Labor-rights organizations mounted an analogous effort, seeking guaranteed protections for workers, but the effort failed in its delivery.

[11] A comparable side agreement covering labor relations, the North American Agreement on Labor Cooperation, also went into effect (Aspinwall, 2017).

[12] A separate 1906 bilateral agreement requires U.S. deliveries of 60,000 af (74 million m^3) annually to Mexico, upstream of Fort Quitman (Viña, 2005).

outraged, demanding the U.S. IBWC act more forcefully. During the crisis, regional stakeholders—mostly farmers—exerted political pressure to resolve the crisis and restore water deliveries. U.S. Congressional resolutions were filed condemning Mexico, but the two nations' presidents (G. W. Bush and Vicente Fox) personally intervened to resolve the water crisis. A subsequent study of the stakeholders found that Texan and Mexican farmers ultimately came to appreciate that, while apparently in conflict, they would benefit from cooperation in their shared ecosystem (Walsh, 2004).

In addition to presidential intervention, to help address the situation, IBWC negotiated new minutes and investments in water efficiency. Diplomacy prevailed, though with a timely assist from nature. Hurricane-related heavy rainfall subsequently helped Mexico clear the water debt in 2005 (Carter et al., 2018).[13] Dams filled; debts were cancelled. IBWC did initiate measures to focus on sustainable management of the over-allocated and drought-prone basin. Minutes 307 and 308 called on the two countries to develop a framework to allow the parties to manage the basin's drought-related emergencies (Mumme, 1999; Viña, 2005). The crisis that peaked in the summer of 2002 eventually benefited from a wet-weather period that allowed Mexico to clear its water debt with the U.S. But subsequently, new shortages occurred. This chronic uncertainty continues to madden Texas water interests. Yet inspired by riparian achievements further west, the two countries have now convened working groups under the mantle of IBWC's International Watershed Initiative to study ways to enhance the reliability of Mexico's treaty-water deliveries. Although water debts have been incurred in more recent five-year cycles (e.g., 2010–2015), in 2016 Mexico was on course to fulfill its payments in the current cycle which ends in October 2020 (Carter et al., 2018).

During the 1990 s–2000 s crisis, an extraordinary intervention extending even to the presidential level was necessary to ease tensions. But it was the robustness and suppleness of the treaty and the institution of IBWC/CILA that deployed the necessary flexibility to address longer-term sustainability of Rio Grande water management through actions such as Minutes 307 and 308.

Progress on water-sharing on the Rio Grande, while slow and incremental, continues to occur. If anything, the record shows that diplomatic achievements and institutional innovations on other transboundary rivers can be transitive; these innovations have informed stakeholder views and diplomatic thinking about how differences in treaty interpretation and domestic water management may be better addressed.

4.5. *Transboundary aquifer assessment program*

The Transboundary Aquifer Assessment Program represented a significant undertaking in the sharing of data and the co-production of knowledge between the U.S. and Mexico. Here we see science foregrounded in the exercise of hydrodiplomacy.

As noted in the case of the water debt crisis on the Rio Grande, initiatives to address mounting pressure on U.S.-Mexico transboundary aquifers began in the early 2000s. That period featured binational tension over lower-Rio Grande water-sharing (as outlined in the previous section). New Mexico Senator Jeff Bingaman sponsored transboundary-aquifer legislation that originally involved only New Mexico and Texas. Arizona subsequently joined and the Transboundary Aquifer Assessment Act (TAAA) was signed into law in 2006. Early versions of the legislation (S. 214 – 17) charged the U.S. Geological Survey (USGS) with coordination of the program and sought authorization of $50 million over the 2006–2015 period for federal projects, technical assistance, and grants. The final version (S. 214 – 109th) retained the $50 million authorization, though it left appropriations[14] up to future federal budget-making. Notably, the TAAA charged that, "The Secretary [of the Interior], in consultation and cooperation with the Participating States, the water resources research institutes[15], and other appropriate entities in the United States and Mexico, and the IBWC, as appropriate, shall carry out the United States-Mexico transboundary aquifer assessment program to characterize, map, and model priority transboundary aquifers along the United States-Mexico border at a level of detail determined to be appropriate for the particular aquifer." The program's sole purpose has been to assess the aquifers, not to administer or regulate them.

All that the U.S. legislation could do was authorize U.S. involvement in binational aquifer studies; it could not mandate Mexican involvement. The main legislative provisions involving Mexico were that funds could be directed to Mexican parties, though there had to be a one-to-one match, and that IBWC would be consulted as needed. It quickly became apparent that IBWC would play a significant role because Mexico's position is that all border water matters, including groundwater, must go through CILA, even though groundwater was not mentioned in the 1944 Treaty and only minimally mentioned in Minute 242. With institutional and financial support of Mexico's National Water Commission (known as CONAGUA), the CILA—perhaps more readily than IBWC in the U.S.—willingly joined the technical-assessment process. After considerable negotiations, the "Joint Report of the Principle [sic] Engineers Regarding the Joint Cooperative Process United States-Mexico for the Transboundary Aquifer Assessment Program" was signed in August 2009, and Mexico agreed to study the four aquifers initially identified by the TAAA (Santa Cruz and San Pedro in Arizona and Sonora; and Mesilla in New Mexico and Hueco Bolson in Texas—both shared with Chihuahua).

Key to the subsequent study activities was Mexico's position that border groundwater matters must go through CILA, though funding is primarily from CONAGUA. This intragovernmental dialogue illustrates adaptive flexibility, also seen in the treaty via interpretations made through minutes. The implementation of TAAP in Mexico is solely the province of CONAGUA and CILA, with technical assistance from Mexican universities and agencies.

Given the two countries' asymmetric water-management regimes, U.S. arrangements differed from those in Mexico (Megdal and Scott, 2011). While IBWC played the official role, TAAP's dynamism resulted from the partnership between the USGS in the lead and three state Water Research Institutes (WRIs) as designated partners with shared funding. Within these institutional learning arrangements, university teams contributed significantly to the flexible approach that allowed the Arizona-Sonora component, in particular, of TAAP to advance rapidly. The WRIs potentially play an important role in any binational sharing of U.S. funding in that they are authorized to fund work in Mexico, subject to the matching requirement of the TAAA; the USGS is not so authorized. The arrangement on the U.S. side underscored the program's core scientific mission. Groundwater management and policy were understood as national and subnational matters.

The "boundary spanning" and scientific-input roles of university WRIs were crucial. The Arizona team included deep contextual knowledge, institutional background (including institutional memory), social-science and policy perspectives to complement hydrogeology, experience in a range of transboundary contexts, and the involvement

[13] Tragically and ironically, it was in such a storm in 2008 that IBWC commissioner Carlos Marin and CILA commissioner Arturo Hererra perished in a plane crash while assessing flooding of the Rio Grande. Passenger Jake Brisbin, Jr. of the Rio Grande Council of Governments and pilot Matthew Peter Juneau also died in the crash.

[14] Federal "authorizations" are the upper limits Congress can provide. The actual amounts provided are known as "appropriations."

[15] Per the 1984 State Water Resources Research Act, each U.S. state plus the District of Columbia, Puerto Rico, the U.S. Virgin Islands, and Guam maintains a federally-supported Water Research Institute (WRI). These institutes are at public universities.

of U.S. and Mexican graduate students —all with supportive and flexible USGS team members (Callegary et al., 2018). Two authors of this paper (Megdal and Scott) had firsthand experience with TAAP, thus assuring that social learning informed the binational team. The rigorous USGS peer-review process was followed so that the bilingual English-Spanish San Pedro report (Callegary et al., 2018) could carry the USGS logo along with those of other partners.

Whereas efforts to date have focused on inventorying and harmonizing available data and information, future work could involve joint, binational groundwater modeling. Such modeling, however, requires years of predictable funding—something difficult to achieve given governmental budgeting processes. This exemplifies the sort of hurdle that can impede binational scientific inquiry, even when prioritized by both countries.

4.6. Minutes 316, 319, and 323 and ecological restoration, Colorado River Delta

Over the past decade, three minutes to the 1944 Treaty—all implemented under the auspices of IBWC (IBWC, 1944)—commit the two nations to protect a Colorado delta ciénega, or wetland (Minute 316) and restore riparian habitat along the Colorado River's course in Mexico (Minutes 319 and 323). These three agreements illustrate precedent-setting changes in: IBWC's concerns and operations; the engagement of NGOs in crafting and funding agreements; and the provision of environmental-science expertise to support delta restoration.

Minute 316 (April 2010) resulted in the first transboundary flow of water for ecological purposes. The resulting flows were directed toward the Ciénega de Santa Clara (hereafter, Ciénega) on the Colorado delta plain. This ciénega, now a 6500-ha (16,000 acres) wetland and habitat for endangered marshbirds and desert pupfish, was inadvertently created in 1977 by the diversion of slightly brackish groundwater from the Wellton-Mohawk Irrigation and Improvement District in Arizona. Diverting the water through a canal, instead of channeling it to the river, helped the U.S. meet its obligations to supply Mexico with water that met the quality standards established. Another solution to the Minute 242 water-quality standards was the Yuma Desalting Plant (YDP), though the plant was in "mothballs" because the Lower Basin states found it cheaper to dilute the river's water by diverting more from Lake Mead upstream.

As drought persisted in the Colorado River Basin, the Metropolitan Water District of Southern California, the Central Arizona Project, and the Southern Nevada Water Authority—the three major water providers in the lower basin—proposed a trial operation of the YDP. But even a pilot run, at one-third capacity, would decrease both the flow and quality of water flowing to the Ciénega de Santa Clara. Environmental groups opposed the plan until a deal was achieved (CSC Workgroup, 2005). A trial operation of the YDP could occur only if no harm would come to the Ciénega. This seemingly-impossible goal was met by Minute 316, where "arranged water" (30,000 af) would be supplied to the Ciénega in an amount equal to that diverted to the YDP for its trial operation. One-third of the "arranged water" would be supplied by U.S. water agencies, one-third by CONAGUA, and one-third by environmental NGOs (IBWC, 2010). Scientific monitoring would evaluate the trial operation's environmental effects. Minute 316 marked the growing involvement of environmental groups and scientists in transboundary water management. It explicitly allocated water for the environment and established the precedent for the three-way sharing of responsibility for environmental water.

Minute 319 (November 2012) resulted from persistent dry conditions in the basin and a 2010 earthquake in in the delta. The provision of environmental flows tagged along, at Mexico's insistence and was strongly supported by both U.S. and Mexican environmental groups. The environmental flows of 195 million m^3 (158,000 af) during the five-year term of the minute constituted a small part of the Minute 319 agreement. Following the precedent set by Minute 316, the environmental water was provided equally by each of the three parties. The "pulse flow" delivered water aimed to simulate a natural spring flood (Mumme et al., 2018). Minute 319 also required a program to monitor the hydrologic and ecological effects of the flows. The restoration and scientific monitoring programs are funded, in equal proportions, by the U.S. and Mexican governments and the NGOs. Overall, Minute 319 is considered the highlight in the recent U.S.-Mexico water relationship, as it demonstrated that both countries could manage the river in mutually-beneficial ways. It marks the first time in decades that the river reached the Sea of Cortez, its natural destination.

Minute 323 (September 2017), like Minute 319, continues a program to provide environmental flows to the delta for the minute's nine-year duration.[16] It was made possible through years of negotiations among federal and state representatives from both governments, and input from binational water users, researchers, and NGOs (Carter et al., 2018; IBWC, 2017). Again, the flows are to be provided equally by the U.S., Mexico, and the NGOs. The U.S. commitment, as in Minute 319, will be met by savings from U.S.-funded improvements in Mexican irrigation efficiency. The NGO commitment will be met by deliveries of water from water rights purchased or leased from Mexican farmers. No pulse flow is prescribed by Minute 323, but rather environmental flows are delivered to the restoration sites through irrigation canals. The Minute also sustains and strengthens the work of the IBWC's Binational Environmental Work Group, originally formed to work on Minute 319, consisting of representatives from the U.S., Mexico, and environmental non-profit organizations (Spener, 2012). Minute 323 is thought to represent the most robust effort undertaken to promote restoration of the delta in terms of dedicated flows and funding (Lewis, 2019).

Collectively, the minutes document flexibility in governance arrangements, allowing for new actors—namely, the environmental NGOs—to participate in governance. While the NGOs still are not at the IBWC negotiating table, their voices are heard in side conversations and through the Mexican delegation. They are explicitly recognized in the minutes and through their participation in the Binational Environmental Work Group (BEWG). Their influence is attributable to their willingness to: share the provision of water, provide the funding for restoration and monitoring projects, and offer scientific expertise—either from within their organizations or from academic scientists. This novel design of the BEWG provides for long-term, sustained interactions and social learning among stakeholders. With set expiration dates, the process also encourages adaptability and evaluation. Notably, Minute 323 is set to expire at the end of 2026, just when the Colorado River Interim Guidelines (established for the U.S. basin states) expire. The coincidental timing links discussions of future water-management guidelines among the U.S. basin states to future negotiations with Mexico.

In spite of attempts at inclusivity, tribal stakeholders have not been sufficiently included in formal consultation and network processes. The 1944 Treaty includes only the two neighboring nations as parties with standing and they are not required to consult with affected sovereign tribal nations (Lewis, 2019). According to one analysis, the Cocopah Indian tribe and other delta stakeholders "have not received due representation during the negotiations of past environmental flow programs," indicative of "a major failure of the entire Minute process to date (Lewis, 2019: 255)."

5. Discussion

The six case studies above have illustrated turning points for the processes discussed. But how have they demonstrated adaptive governance? What are the relative or combined roles of science and

[16] The IBWC's Environmental Work Group predates Minute 323, with antecedents going back at least as far as the 2009 DOI/IBWC Joint Memorandum; it was established prior to Minute 317 (2010: see page 2).

Table 1
Adaptive Governance Indicators and Science/Diplomacy Inputs at Key Turning Points.

Cases	Adaptive Governance Indicators: Social learning & co-production of knowledge (I_1)	Sustained & iterative relationships	Flexibility & innovation in	State & non-state actor networks	Foundational role of Treaty of 1944 & IBWC/CILA	Science &/or diplo. (S, D)	Principal achievement	Barriers & challenges
Treaty of 1944 & IBWC/CILA			X	X	X	D	Creation of a robust treaty & minute process, and a joint institution to implement & interpret it	Integration of public participation in decision-making processes. Limited transferability of lessons learned in one basin to other basins
Salinity Crisis of 1961-1973	X		X		X	S, D	Minute 242	Treaty of 1944 did not explicitly address water quality, but Minute process provided the flexibility for IBWC to innovate a solution in Minute 242
NAFTA & environmental side agreements			X	X		D	Creation of BECC, NADBank, & CEC to improve border infrastructure & investigate environmental complaints	Transitions in national administrations; Chronic resource shortages
Rio Grande water debt crisis			X		X	D	Minutes 307 & 308	The treaty does not define "extraordinary drought" and the terms of the allocation of the waters of the Rio Grande are not straightforward
Transb. Aquifer Assessment Project	X	X	X	X	X	S	Data-sharing to inventory & harmonize available data from both countries	Lack of synchronicity and lack of multi-year, predictable funding impeded potential for binational groundwater modeling, geohydrological assessment & mapping
Minutes 316, 319 & 323	X	X	X	X	X	S, D	Environmental flows to Colorado delta wetlands, expanded capacities for sharing reservoir storage & sharing water shortages b/w the two countries	Challenge to find sufficient water rights to maintain minimum flows for Colorado Delta restoration, and to expand current restoration efforts to new areas within the Delta

S = Strong role for Science.D = Strong role for Diplomacy.S, D = Strong role for both factors.
Light gray indicates selected adaptive water governance indicators.Dark gray indicates relative roles of science and diplomacy.Coral indicates achievements and challenges.

diplomacy in each case and overall? What kinds of challenges and barriers do we note in the practice of hydrodiplomacy over a varied set of cases? In this section, we evaluate each case in terms of a) the relative importance of the five adaptive governance indicators in our assessment; and b) the relative roles of science and diplomacy in achieving the outcome in each case. These determinations are based upon the case-study descriptions in the analysis of each case. They are meant to indicate an indicator's relative importance in each context.

Table 1 summarizes our findings regarding adaptive governance and the relative (or combined) roles of science and diplomacy, as reflected in water-governance transitions in the border region.

We highlight five findings:

- i The significance of temporal and spatial context
- ii The expansion of transboundary water-governance capacity in the postwar period
- iii A movement toward inclusion of non-nation-state actors at different scales, and toward a more ecological focus
- iv The linkage of governance-capacity changes across time and space, with each phase building on prior phases
- v Diverse roles played by both science and diplomacy efforts in these cases

First, we find that in the border region, adaptive governance and hydrodiplomacy are temporally and spatially contextualized. The 1944 Treaty has remained both foundational and robust since its signing. The passage of 75 years has not diminished the treaty's potency; rather, the flexibility conferred by the minutes process has allowed that instrument to gain relevance over time. The treaty and IBWC are equally applicable, yet unevenly realized across the geography of the border, demonstrating significant innovation and adeptness in the Colorado River basin, but less of it in the Rio Grande or Tijuana basins.

Second, the turning points in transboundary water governance show the expansion of governance capacity in the postwar decades. The Salinity Crisis, the advent of NAFTA, and the water-debt crisis all demonstrated innovation and a key role for the treaty and IBWC, either in their creation (NAFTA, BECC, NADBank, and CEC) or resolution (salinity crisis, water-debt crisis). However, the other adaptive governance indicators—social learning, sustained relationships, and state/non-state stakeholder networks—are evident in some but not all cases. This suggests that while both science and diplomacy played a role, these three cases were "diplomacy-driven" rather than "science-driven."

Third, in the two most recent turning points we analyze—TAAP and Minutes 319/320/323—the development of fresh governance capacities, understood in normative terms, has a positive directionality. Governance, while still under IBWC auspices, has evolved to be more inclusive of different kinds of actors (academic scientists, environmental NGOs) and at multiple scales (joint commission/federal/state/

local governments). It also has become more co-productive of knowledge based on data-sharing and development of common goals. Governance, as a result, has been fueled by sustained and iterative binational working relationships. For example, the creation of new environmental institutions as part of NAFTA resulted from the pressure from environmentalist groups—non-state actors—who pressured formal negotiators for explicit mechanisms to protect the environment. The creation of BECC and CEC is indicative of innovative governance practice and reflects a topically broadened scope, attached to a commercial treaty. In the most recent cases, TAAP and Minute 319, we see all of the key indicators of adaptive governance in effect, suggesting the expansion of capacity. At the same time, the relative ways in which science and diplomacy are called upon varies in each case, indicating that different "ingredients" are necessary to achieve hydrodiplomatic objectives.

Fourth, our analysis underscores that the above adaptations in the governance process in one basin are influenced by those in another (e.g., from the Colorado to the Rio Grande basin), and that they are connected across time and space and build upon one another—with the treaty and IBWC as constants across the six cases. For example, Minute 319 would likely not have been possible without Minutes 306 and 316. With Minute 306 in 2000, IBWC formally introduced the concept of ecological restoration in its framework. This minute acknowledged IBWC's interest in preserving the riparian and estuarine ecology of the Colorado delta, established a binational technical taskforce, and set the framework for binational collaboration for environmental concerns (IBWC 2000). It recognized a growing collaboration among scientific, academic, and nongovernment organizations in the two countries. As such, Minute 306 helped set the stage for binational cooperation around ecological restoration. Overall, the more inclusive and environmentally-engaged governance practices point optimistically to a potential for more adept and nimble responses to future transboundary water-resources challenges.

Fifth, with respect to the relative roles of science and diplomacy, the turning points we analyzed provide evidence that various science and diplomacy arrangements fit under the broad umbrella of "hydrodiplomacy." In the case of TAAP, the principal objective was co-production of scientific data. In contrast, diplomacy was key to the original 1944 Treaty and IBWC creation, to the signing of NAFTA, and to the resolution of the Rio Grande water-debt crisis. Both science and diplomacy are hallmarks of the Salinity Crisis of 1973 and Minute 319.

In the salinity crisis, scientific assessment that salinization was compromising water quality caused U.S. negotiators to abandon the business-as-usual position that precipitated the need for an accord. In the case of the Colorado delta, hydrological (that is, scientific) assessment of required minimum flows to sustain the wetlands led to early discussions about the feasibility of an environmental-flows agreement. Comparably, scientific monitoring following the pulse-flow release was key to documenting the effectiveness of temporary Minute 319; it led to the institutionalization of environmental flows in permanent Minute 323. At the same time, diplomatic negotiation between Mexico and the U.S. via the IBWC and the binational scientific network gave rise to agreements to other national objectives—such as shortage-sharing (a U.S. goal) and reservoir- sharing (a Mexico goal). In the hydrologically-stressed and over-allocated Colorado River basin, the hydrodiplomacy represented by Minutes 319 and 323 is a notable achievement and presages effective approaches to confronting future transboundary water challenges.

6. Conclusions

In view of the foregoing discussion, we pose three concluding questions. First, what are the most likely future challenges for the U.S.-Mexico border region? Second, what are the implications of U.S.-Mexico hydrodiplomacy beyond the region? And finally, what can the hydrodiplomacy framework, based on adaptive governance, contribute to an understanding of the history of U.S.-Mexico relations around water?

Below, we discuss the key issues that lie ahead for the area in question. Then, we consider how our observations and findings may be generalizable and potentially useful elsewhere.

Two challenges stand out. The first, *climate change*, is a global-scale driving force; the second, *replicability and transitivity*, is a necessary characteristic for extension and adaptation of successes in one part of the region to other areas.

6.1. Climate change

Climate changes projected by mid-century—such as increases in extreme heat, more severe and extended droughts, more frequent and destructive wildfires, and increased likelihood of vector-borne diseases—are likely to continue to be among the most difficult problems the region confronts. Impacts can be expected to include reduced water supply, changes in livelihood and land use, and worsening socio-economic vulnerability. All those changes, in turn, worsen the impact of pandemics such as the 2020 advent of COVID-19. These challenges will test the endurance of effective transboundary governance agreements to date.

6.2. Replicability and transitivity

Interbasin transitivity and replicability of governance arrangements is a challenge the border region faces. As the U.S. and Mexico achieve new strides in transboundary water-governance capacity in the Colorado River basin, how can the same institutions—IBWC/CILA working under the provisions of the Treaty of 1944—develop similar capacities appropriate for the distinct contexts of the Rio Grande and Tijuana transboundary basins? The creation of binational work groups suggests fresh capacities may be developed in those basins yet the experiences of the transboundary Colorado basin suggest that the task will be time-consuming and difficult.

Finally, we ask how the hydrodiplomacy framework is useful to understanding 75 years of relations around water in the transboundary region, and what are some possible lessons or implications of U.S.-Mexico hydrodiplomacy for other transboundary global regions? By honing our theoretical understanding of hydrodiplomacy—which weaves together water diplomacy and science diplomacy frameworks—we can uncover key elements for generalizability. These include the ways in which formal and informal institutions, actors, and networks in the region have evolved fresh capacities for conceptualizing, addressing, and resolving complex water resources issues. Those successes they have achieved were obtained by drawing on scientific and local knowledges at multiple scales.

Adaptive governance, in our view, is a *sine qua non* of hydrodiplomacy and is a means by which hydrodiplomacy is carried out and enacted. To understand the goals, values, and intentions of hydrodiplomacy and the institutions, instruments and mechanisms of adaptive governance lends greater capacity toward and enables replicability of successful outcomes. That insight also helps avoid contentious and divisive outcomes. An appreciation for hydrodiplomacy may thus help reduce the uncertainty of water challenges in the transboundary region, or elsewhere.

The practice of hydrodiplomacy over the last 75 years in the U.S.-Mexico border region underscores the need for both strong fundamentals and flexible and dynamic capacities. In terms of the region's fundamentals, the 1944 Treaty and the IBWC/CILA institution stand as enduring pillars of transboundary water relations. As such, they provide consistent parameters of interactions around water in the region. Both science and diplomacy, in varying degrees and roles, have been invoked and practiced consistently (if unevenly) to achieve ends desired by *each* country and, in the most effective outcomes, by *both* countries. At the same time, the treaty's minute process provides the relevant decision makers flexibility to implement new solutions. In the recent past this largely has been accomplished—in part via increased responsiveness to binational stakeholder groups engaged in sustained relationships, learning from one another, sharing scientific knowledge, and, in the best of cases, developing newly-shared goals. Nevertheless, along with the hydrodiplomatic achievements in the region, significant challenges remain and need to be addressed in the future. For example, how to meaningfully include tribes and vulnerable actors in the decision-making processes; how to add environmental uses to existing water allocations, and how to expand binational cooperation on groundwater.

The implications of the U.S.-Mexico experience for other global transboundary regions in hydrodiplomacy might best be encapsulated by *fundamentals* and *flexibility*. That is, striving to put in place respected rules and institutions, guided primarily by science and hydrological needs, yet responsive to changing conditions and emerging networks of actors. Even while we can identify these "ingredients" in a retrospective assessment for one transboundary region, we recognize that the recipe requires serious adaptation to context and may not be easily replicable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Margaret O. Wilder: Conceptualization, Project administration, Supervision, Methodology, Visualization, Writing - original draft, Writing - review & editing. **Robert G. Varady:** Conceptualization, Project administration, Funding acquisition, Methodology, Visualization, Writing - original draft, Writing - review & editing. **Andrea K. Gerlak:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Stephen P. Mumme:** Writing - original draft, Writing - review & editing. **Karl W. Flessa:** Writing - original draft. **Adriana A. Zuniga-Teran:** Writing - original draft. **Christopher A. Scott:** Funding acquisition, Writing - original draft. **Nicolás Pineda Pablos:** Funding acquisition, Writing - original draft. **Sharon B. Megdal:** Writing - original draft.

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