C. Adaptation Pathways and Application in Water Resources

To identify and summarize similarities and differences in adaptive management principles (e.g., robust decision-making and dynamic adaptation policy pathways), a text search in Web of Science was conducted to identify papers to define each term and explain its applications. Then, case studies using each principle were identified through a text query of the Climate Action and Resilience Plan Database provided by **Consortium for Climate Risk in the Urban Northeast**, which contains over 270 local plans from across the United States. The database was queried using NVivo text analysis software. In instances where case studies could not be found, the literature review was extended to include international examples.

There is a wide variety of adaptive management approaches, many of which build off of each other. It is therefore useful to consider the compatibilities between many of these approaches, rather than viewing them as mutually exclusive options. Within the literature, there are unique distinctions between each approach that make them more or less appropriate under different circumstances; in practice, many communities and utilities have combined features of multiple approaches to best suit their context-specific priorities and climate risks. Additionally, many communities use comparable or compatible adaptation approaches without necessarily specifying the terms included in the table below. The approaches included herein are predominantly used within academic, technical, or planning documents and do not capture the breadth of local and traditional ecological knowledges used as the basis for adaptive management.

The table is color-coded and ordered to highlight connections and similarities between approaches. For example, the backcasting approach is a type of scenario planning; robust decision-making is complementary to dynamic adaptive policy pathways; and real options analysis aligns with adaptive management. While the colors capture overarching similarities, the relationships between these strategies are complex; trade-offs and co-benefits should be thoughtfully considered when determining which approach(es) to employ in adaptation planning.

Strategy	Definition	Features	Case studies
Scenario planning	"The purpose of scenario planning is to allow practitioners to conceptualize stories about alternative futures to improve institutional decision-making and manage for risk and uncertainty" (Cobb and Thompson 2012)	· Exploratory scenarios trace plausible futures but do not make predicts or outline how to achieve a particular desirable future · Compatible with participatory methods	**Tucson Water, Arizona:** a conceptual planning timeline, which extends from 2000 to 2050 (HDR Engineering, Inc. 2013) **Marin County, California:** Sea level rise and storm scenarios for planning (SPUR 2012)
Backcasting approach	"1) the development of desirable images of the future (visions) and 2) a backwards analysis of how these visions can be realized" (van Vleit & Kok 2013)	· A type of normative scenario approach aiming to achieve a particular future · Can include qualitative or quantitative data · Can be combined with exploratory scenarios to increase robustness	**SCENES:** Water scenarios for Europe and neighboring states **Greater New Orleans Urban Water Plan:** provides normative visions of 'urban water corridors'
Robust decision-making (RDM)	"Rather than using computer models and data as predictive tools, the approach runs models myriad times to stress test proposed decisions against a wide range of plausible futures. Analysts then use visualization and statistical analysis of the resulting large database of model runs to help decisionmakers identify the key features that distinguish those futures in which their plans meet and miss their goals" (Lempert 2019)	· Complementary with Dynamic Adaptive Policy Pathways · Combines decision analysis, assumption-based planning, scenarios, and exploratory modeling · Provides decision support under deep uncertainty · Utilizes the concept of "plausible futures" from scenario analysis · Seeks robust strategies (which perform well over a wide range of future scenarios) rather than optimal strategies	**Colorado:** Uses RDM to support long-term water resources planning for the Colorado River Basin (Groves et al. 2019) **Southern California's Inland Empire Utilities Agency:** Used RDM to evaluate impacts of climate change on long-term urban water management (Lempert & Groves 2010)
Adaptation pathways	"...an analytical approach for exploring and sequencing a set of possible actions based on alternative external developments over time" (Haasnoot et al. 2013)	· Provides a pathway map useful in visualizing options over time · Includes adaptation tipping points and presents possible options after a tipping point has been reached using adaptation trees · Provides information on path dependencies · Presents multiple routes to achieve the same desired outcome · Quantitative targets are necessary to determine the success of a pathway or action	**Miami, Florida:** estimated economic feasibility of multiple adaptation pathways **Lakes Entrance, Australia:** tested the use of adaptation pathways to address sea level rise and conflicts regarding coastal development between city officials and residents. The process indicated that identifying triggers and tipping points that are socially salient to residents is critical to success because it highlights unacceptable impacts for people, provides participants with a sense of ownership over scenarios, and builds consensus for action (Barnett et al. 2014)

Strategy	Definition	Features	Case studies
Adaptive policymaking	"...a stepwise approach for developing a basic plan, and contingency planning to adapt the basic plan to new information over time" (Haasnoot et al. 2013)	· Complementary to adaptive pathways · Includes trigger points and signposts to determine if the plan is meeting goals · A plan to realize a decision-maker's normative vision · Provides a broad framework rather than clear guidance	**Netherlands:** developed a national civil aviation policy
Dynamic adaptive policy pathways (DAPP)	"This integrated approach includes: transient scenarios representing a variety of relevant uncertainties and their development over time; different types of actions to handle vulnerabilities and opportunities; Adaptation Pathways describing sequences of promising actions; and a monitoring system with related contingency actions to keep the plan on the track of a preferred pathway" (Haasnoot et al. 2013)	· A combination of adaptive policymaking (contingency planning, triggers, and monitoring) and adaptation pathways (pathway maps)| · Focuses on keeping options open and including adaptation over time · Strength: more comprehensive than either strategy individually · Weakness: more complex than either strategy individually	**Netherlands:** developed pathways for water management of the Rhine Delta (Haasnoot et al. 2013) **Wellington, New Zealand:** Sea level rise thresholds evaluated using DAPP and test strategy for managed retreat of water infrastructure developed to identify options to maintain services under varying sea level rise rates (Kool et al. 2020)
Flexible adaptation pathways	"Flexible adaptation pathway(s) is a relatively loose term used to look at how building flexibility in to adaptation can help to manage the long-term and uncertain nature of climate change impacts" (Moss & Martin 2012)	· General term for a suite of approaches rather than a specific methodology · Uses risk-based decision frameworks, thresholds, and/or trigger points · Interchangeable with 'decision pathways'	**Hampton Roads, Virginia:** using the framework to determine low-cost, no-regret actions in the present, while investigating strategies to implement in the future (Hampton Roads Planning District Commission 2013) **ConEdison, New York City:** tracking conditions affecting system resilience with pre-defined thresholds (ConEdison 2019) **New York City Panel on Climate Change:** advancing tools and methods for flexible adaptation pathways (Rosenzweig & Solecki 2019)
Trigger points	"A trigger specifies the conditions under which a pre-specified action to change the plan is to be taken" (Haasnoot et al. 2013)	· Part of adaptive policymaking approach · Strength: clarifies timeframes for action	**Marin County, California:** determining trigger points for compromised septic leach fields (Marin County Community Development Agency 2018) **Sacramento, California:** using trigger points to determine water-efficiency upgrade installation (City of Sacramento 2012) **Southwest Australia:** trigger points for decisions established along the protect-accommodate-retreat coastal adaptation spectrum (Grace & Thompson 2020)
Adaptation tipping point(s)	"...the point at which a particular action is no longer adequate for meeting the plan's objectives" (Haasnoot et al. 2013)	· Part of adaptation pathways approach · Weakness: difficult to detect with lead time · Also referred to as thresholds	**Mertarvik, Alaska:** population thresholds for relocation efforts to trigger school, airport, and post office services (Newtok Planning Group 2011) **Laguna Woods, California:** thresholds set to determine no-regret, more aggressive, and very aggressive strategies (City of Laguna Woods 2014) **Metlakatla Indian Community, Alaska:** thresholds set for water levels in the municipal supply to trigger water conservation practices (Scott et al. 2017) **New Zealand:** Adaptation tipping points may include failed performance of an action or changes in community coping capacity (Stephens et al. 2018) **Netherlands:** Applies tipping points to water management efforts to defend against floods, protect drinking water, and protect Rotterdam Harbor (Kwadijk et al. 2010)
Adaptive management	"Adaptive management [is a decision process that] promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process" (Williams et al. 2009)	· Facilitates social and institutional learning · Compatible with participatory processes · Can be resource-intensive	**Ocean Beach, California:** includes ongoing monitoring of conditions as they develop over time (SPUR 2012) **Broward County, Florida:** setting short-, intermediate-, and long-range goals and establish adaptive management implementation strategies for water resources (Broward County 2015) **Thurston County, Washington:** iteratively updating the plan with new climate information and community input (Thurston Regional Planning Council 2018) **Clarence, Australia:** The Clarence City Council included evidence-based monitoring and evaluation as a requirement for adaptation measures to allow for necessary revisions and updates based on real-world changes in environmental and socioeconomic conditions (Abunassr et al. 2013)

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Adaptive co-management	"Adaptive co-management is an emergent governance approach for complex social–ecological systems that links the learning function of adaptive management (experimental and experiential) and the linking (vertically and horizontally) function of co-management" (Plummer et al. 2012)	· Combination of adaptive management and co-management · Strength: emphasizes collaboration, pluralism, and communication · Challenge: more resource-intensive and complex than either strategy individually	**England:** enabling freshwater ecosystem protection and livelihood sustainability through uncertain water futures (Whaley & Weatherhead 2016)
Real options analysis	"Real Options Analysis quantifies the investment risk associated with uncertain future outcomes. It is particularly useful when considering the value of flexibility of investments. This includes the flexibility over the timing of the capital investment, but also the flexibility to adjust the investment as it progresses over time" (Watkiss et al. 2013)	· Used to determine whether to invest now or at a later point in time · Aligns with adaptive management · Utilizes decision trees for visualization · Strength: informs large investment decisions through economic analysis of the value of flexibility and information · Weakness: complexity requires expert knowledge and resources · Few examples of application to adaptation	**London, England:** Multi-stage scenario trees for water supply planning for water utilities (Erfani et al. 2018)
Decision scaling	"The use of a decision analytic framework to reveal the scaling of climate information that is needed to best inform the decision at hand. In decision scaling, the premise is that discussion of appropriate downscaling methods should follow and be informed by the formal modeling of the decision of interest" (Brown et al. 2012)	· Links vulnerability assessment with climate projections · Utilizes a wide variety of climate information sources for decision-making · Uses stochastic analysis · Stakeholder-centered, risk-based framework	**BUA Knowledge Platform:** eco-engineering decision-scaling for water management