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Restoration of contaminated ecosystems: adaptive management in a changing climate

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Title: Restoration of contaminated ecosystems: adaptive management in a changing climate

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Abstract

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Three case studies illustrate how adaptive management (AM) has been used in ecological restorations that involve contaminants. Contaminants addressed include mercury, selenium and contaminants and physical disturbances delivered to streams by urban stormwater runoff. All three cases emphasize the importance of broad stakeholder input early and consistently throughout decision analysis for AM. Risk of contaminant exposure provided input to the decision analyses (e.g. selenium exposure to endangered razorback suckers, Stewart Lake; multiple contaminants in urban stormwater runoff, Melbourne) and was balanced with the protection of resources critical for a desired future state (e.g. preservation old growth trees, South River). Monitoring also played a critical role in the ability to conduct the decision analyses necessary for AM plans. For example, newer technologies in the Melbourne case provided a testable situation where contaminant concentrations and flow disturbance were reduced to support a return to good ecological condition. In at least one case (Stewart Lake), long term monitoring data are being used to document the potential effects of climate change on a restoration trajectory.. Decision analysis formalized the process by which stakeholders arrived at the priorities for the sites, which together constituted the desired future condition towards which each restoration is aimed. Alternative models were developed that described in mechanistic terms how restoration can influence the system towards the desired future condition. Including known and anticipated effects of future climate scenarios in these models will make them robust to the long-term exposure and effects of contaminants in restored ecosystems.

Key Words: Adaptive management, contaminated ecosystems, climate change, case studies

Implications for Practice:

- The restoration of contaminated ecosystems or those impaired by industrial activities provide case study examples of adaptive management
- The methodical decision analyses provided during adaptive management is not trial and error, but a priori defining of models that can be used for restoration action
- Case studies illustrate the effectiveness of broad stakeholder input, long term monitoring, and ecological risk assessments, all established early in the process.
- Long term monitoring already conducted in some cases provides useful information for predicting effects of climate change on restoration trajectories.

Introduction

It has been persuasively argued that adaptive management (AM) is key to addressing uncertainties related to global climate change (GCC), especially as related to rehabilitation of contaminated lands (Landis et al. 2013; Rohr et al. 2013). A 2014 workshop sponsored by the Society for Ecological Restoration and the Society of Environmental Toxicology and Chemistry, convened to define the current state of knowledge for restoring contaminated ecosystems, further emphasized the importance of AM (Farag et al. 2016). There, Rohr et al. (2016) emphasized that AM must be implemented early in the assessment stage and maintained throughout the life of the restoration (Hull et al. 2016) in an iterative fashion (Kapustka et al. 2016) if its benefits are to be

realized, although Hooper et al. (2016) recognized that funding for the necessary monitoring often falls short. The uncertainty of effects of GCC on physical and biotic processes combined with exposure and mobility of contaminants speak strongly to the need for an AM framework during restoration planning. By explicitly evaluating competing models, not only will managers learn how GCC is affecting restoration outcomes, they will be able to quickly adjust management to produce better results as initial uncertainties resolve.

The goal of this manuscript is to discuss AM in detail as it relates to restoration of contaminated ecosystems. Case studies highlight the variety of ways AM can successfully be used by practitioners. Further, we suggest ways in which uncertainty associated with GCC can be integrated into restorations through the use of an AM framework.

AM is often described as a method to learn from and ultimately overcome uncertainty in resource management. By developing alternative mechanistic models (active AM), a deeper understanding of system dynamics is achieved, as well as a clear and defensible management direction. Recent reviews have found that despite its promise, examples of appropriate and successful use of AM are rare in the published literature (Westgate et al. 2013; Williams & Brown 2014). A common misconception confuses trial-and-error management with AM, but the former includes distinctly fewer opportunities for learning (Lyons et al. 2008). In reality, a continuum of tradeoffs in effort between learning and resource management can be described (Williams 2011); even management that includes a single mechanistic model can fit into an

adaptive framework (passive AM) if monitoring is used to evaluate that model and update it as necessary to be consistent with data analyses.

AM is a special case of structured decision making, when competing hypotheses describe the outcome of management actions to achieve objectives (Lyons et al. 2008). In the context of ecological restoration of contaminated ecosystems, management actions are undertaken to address hazards identified in a risk assessment and to achieve the attributes of a restored ecosystem (Wagner et al. 2016). AM requires that there be clear priorities that address stakeholder concerns, alternative management options, and the consequences of the management options should be described in mechanistic terms to facilitate learning (Figure 1, Problem Formation Panel). Stakeholder input throughout an AM process informs objectives, expressed as a desired future condition. To incorporate AM when restoring contaminated ecosystems, an ecological risk assessment is added to inform the problem formation and evaluation criteria processes (Figure 1, Hazard Identification panel). The potential hazard in contaminated ecosystems requires an ecological risk assessment be performed with specific steps needed to address risk from multiple pathways (Figure 1, Hazard Identification panel). The extent of complexity needed for the ecological risk assessment is generally related to the type and extent of contamination in the ecosystem.

Monitoring is a key component of AM (Hooper et al. 2016); attributes measured must be related to outcomes of the mechanistic models (Hutto & Belote 2013). By reevaluating key relationships as data permit, competing models can be assessed and those not supported

discarded. Monitoring can be focused on remaining models at reduced cost. Monitoring in contaminated ecosystems is critical due to potential hazard exposure (Figure 1, Hazard Identification, Evaluation Criteria panels, and Model Selection panels).

In the following three case studies we describe the ways in which AM has been used in ecological restorations that involve contaminants. Contaminants addressed in these case studies include mercury (Hg), selenium (Se) and the suite of contaminants and physical disturbances delivered to streams by urban stormwater runoff. Note: the assessment of risk to contaminant exposure through time can distinguish restoration of contaminated ecosystems from restoration of other types. We introduce the ecological risk assessment topic in this manuscript, but for a more complete description of steps involved in risk assessment the reader is referred to U.S. EPA (1992).

Case study: mercury in the South River

Ecological risk assessment generally has three major steps: problem formulation, hazard and exposure assessment, and risk characterization (Figure 1). In the problem formulation step existing data are evaluated and the requirements for the assessment are determined, including available funding, timeframe, and land use post-remediation. Toxicological information on the contaminants is evaluated along with the potential for important receptors (e.g., humans and wildlife) to be exposed to contaminants. The risk characterization step then compares the hazard and exposure information to determine the risk of harm (U.S. EPA 1992).

Restoration and stakeholder input are not typically incorporated into problem formulation but occur prior to or in concert with the development of risk management actions, which can create problems for risk assessors and risk managers. Such a problem was encountered in the development and design of remedial options to address legacy mercury residing in banks of the South River, Virginia (Figure 2). Studies had shown that a relatively high proportion of the continued loading of mercury to the South River was due to bank erosion. One of the preferred remedial options was to undertake river-bank stabilization to reduce or eliminate continued erosion of mercury-laden bank soils into the river (Foran et al. 2015). As the preliminary remedial design began to evolve, it was shared with a variety of stakeholders, including those whose property adjoined the South River. Stakeholders raised concerns about whether the design would allow preservation of old-growth trees and other valued elements of the river banks. The preliminary design underwent significant change owing to the input from these important stakeholders (Table 1). Currently the discussions continue on how the remedial design can incorporate the input from the stakeholders while still addressing the need to reduce or eliminate continued erosion of mercury-laden river-bank soils. These actions illustrate how preservation and ultimately restoration of valued ecological resources factored into changes in remedial design with the help of an AM process. It also is a very clear example of the need to incorporate restoration-based considerations into the problem formulation step.

The South River case study illustrates the steps needed to implement AM in a restoration plan (Foran et al. 2015; Landis et al. 2016). . The first step established a decision framework that

specified the criteria used to evaluate mercury remediation and achieve ecological benchmarks (e.g., habitat preservation or creation). Processes for determining the objectives of AM often take the form of formal decision analysis (Convertino et al. 2013), such that they take into account the priorities of the entire range of stakeholders (Williams & Brown 2014). As a result of including stakeholder input, alternative desired outcomes, e.g, an emphasis on preservation of habitat versus solely Hg remediation, were included in modeled alternatives. Practical considerations, including ability to implement the action and its support among stakeholders (especially the landowner(s) on whose property the restoration is being undertaken), are also part of the evaluation criteria. Second, weights for the relative values of the criteria were established and included (1) effectiveness, (2) ecological effects, (3) implementability, and (4) cost. Third, models were developed to relate hypothesized system drivers to the criteria. Finally, models were linked to hypothesized effects of management actions (Foran et al. 2015; Johns et al. 2016). As a result of this process, healthy trees of 20.32 cm (8 inches) that are 137 cm tall (DBH or 4.5 feet) or greater, including those on the river bank where their roots were exposed at mid to low water, will be preserved because they provide fish habitat (exposed roots in the river) and help to reduce temperature increases during the summer months. Dead or diseased trees, or those which might present a risk to people using the river or walking along the bank will be removed regardless of size. All of these determinations changed the original design to remove all trees and vegetation from the river bank, either cap or excavate contaminated soils, regrade to a gentle

slope, place a rock toe along the newly remediated bank area to armor against water shear during flooding, and revegetate.

As a result of developing the restoration in the context of AM, a clear path exists in which GCC can be factored into the analysis (Table 1), in particular via the ecological effects weights. Models of system drivers could include climatic variants anticipated for the area. For example, stream flow estimates based on a range of GCC-induced precipitation models could be included in mechanistic models and evaluated for consistency with observed flows and Hg-mobilization. Further, the increased importance of temperature-moderating effects of streambank vegetation can be factored into ecological effects weights.

Case Study: Stewart Lake selenium

Stewart Lake Waterfowl Management Area in northeastern Utah is an approximately 200 hectare wetland adjacent to the Green River, managed by the Utah Division of Wildlife Resources. Although primarily managed as migratory bird habitat since 1936, it is also important habitat for endangered fish (razorback sucker (*Xyrauchen texanus*), bonytail (*Gila elegans*), and Colorado pikeminnow (*Ptychocheilus lucius*)). Beginning in the 1980s, Stewart Lake received irrigation drain water containing concentrations of selenium potentially hazardous to fish and wildlife, ultimately leading to elevated selenium concentrations in sediment, water, fish, wildlife, and other biota (Stephens et al. 1988, 1992). By the 1990s, the U.S. Fish and Wildlife Service determined that AM was the appropriate remediation strategy to protect fish and wildlife. The objective of the AM plan was to implement a cost-effective method for

remobilization and removal of selenium from dry surface sediments of Stewart Lake and ultimately to reduce the selenium hazard to waterfowl and endangered fish. Federal agencies initiated the management plan during the spring of 1997 by first building numerous engineering controls to manage water flowing into and out of the lake. Inlet and outlet channels with water control gates were constructed to facilitate removal of selenium from Stewart Lake sediments (Figure 3). A subsurface drainage-collection pipeline prevented diffuse seepage from irrigated fields containing potentially hazardous concentrations of selenium from entering the wetland, and irrigation return flow drains were diverted around Stewart Lake and put directly into the Green River. Following construction of these engineering controls, U.S. Geological Survey and Bureau of Reclamation developed a long-term operation and environmental monitoring plan based on results from a flood-plot experiment (Naftz et al. 2005). The operation plan focused on flooding the wetland during spring snowmelt runoff, dissolving sediment bound selenium, and flushing the wetland back into the river. The environmental monitoring plan includes an agreement to periodically assess water, sediment, fish, and plankton selenium concentrations and review the course of action according to an AM plan.

Through the first decade of the AM plan, there was a slow downward trend in sediment selenium concentrations, with sharper declines following years of higher Green River flows. Data collected from 2005 to 2011 demonstrated a decreasing concentration of water column selenium at all sites within Stewart Lake. Despite this progress, the mean sediment selenium concentration for the wetland in 2012 was still twice as high as the remediation goal of 4 $\mu\text{g/g}$. In

addition, plankton and whole fish (common carp) selenium concentrations were similar among years from 1995 to 2005 and continued to exceed thresholds for potential selenium effects (health, reproductive, teratogenesis, or survival) in birds and fish. Whole body fish selenium concentrations ranging between 4 and 9 $\mu\text{g/g dw}$, which Stewart Lake fish frequently exceed, have been associated with severe effects in juvenile fish, edema in offspring, and other reproductive effects (U. S. Environmental Protection Agency (U.S. EPA) 2014). Stakeholders continue to meet at least annually to discuss alternative restoration models for the wetland, annual sampling needs, and changes in management necessary to meet the sediment selenium concentration goal.

Recently, important steps in endangered fish recovery have occurred at Stewart Lake under the AM plan. Thousands of wild razorback sucker larvae have grown to juvenile sizes in Stewart Lake and emigrated to the river – a first in many decades (Schelly et al. 2016). In addition, the first reproduction of stocked bonytail in the upper Colorado River occurred in Stewart Lake in 2015 (and again in 2016) (Bestgen et al. 2017). These events demonstrate that the AM plan is a critical part of endangered species recovery in the Green River basin.

Selenium uptake into endangered fish is an important benchmark for floodplain management and for evaluation of the AM alternatives. Whole body fish tissue analysis demonstrates that drier conditions at Stewart Lake may increase fish uptake rates of selenium and uptake rates are apparently declining over time (McAbee, unpublished data). A drier Stewart Lake under GCC scenarios will be an important AM consideration going forward; decreased

river flow and increased risk of drought (Udall and Overpeck 2017) may lessen the progress of selenium remediation under the AM plan. As a result, this AM plan and associated monitoring efforts that were instituted 15 years ago will help assess effects of GCC on restoration alternatives. Stewart Lake provides examples of stakeholders working together to implement an AM plan, and the usefulness of the monitoring data for purposes not fully anticipated initially, e.g. GCC.

Case Study: Urban Stream Restoration

The Little Stringybark Creek (LSC) project is an ongoing catchment-scale ecological restoration experiment in Melbourne, Australia. The project aims to restore an urban stream ecosystem by reducing the impact of urban stormwater runoff (Walsh et al. 2015). Usual approaches to managing urban stormwater involve routing it directly into streams, with negative impacts on stream water quality and ecological health (Burns et al. 2015). Widespread degradation of urban streams has spurred large investments in restoration programs that usually involve increasing in-stream habitat complexity or replanting riparian vegetation. However, this does little to address the cause of stream degradation, namely alteration of land use and drainage pathways across catchments. Effective restoration thus may require actions at the catchment scale (Walsh & Fletcher 2015).

The LSC project is testing the implementation of dispersed catchment-scale stormwater control measures (SCM) to improve flow and water quality regimes and hence stream ecological condition (Walsh et al., 2015). The SCM interventions designed to capture and retain runoff

from impervious surfaces included rain gardens (infiltration and bioretention systems), household rainwater tanks, and larger-scale harvesting and infiltration systems (Figure 4). The goal was to mimic the hydrology of nearby forested catchments that support streams in good ecological condition (Table 1).

The upper 2 km² of the LSC catchment is an urban mix of residential housing, commercial and industrial precincts, while downstream is predominantly low density, rural-residential areas. Three reference and three control streams, in addition to LSC, that have been monitored since 2001 for water quality, algal biomass and community composition, and macroinvertebrate composition (Walsh et al, 2005) are used in this AM plan. The Before-After-Control-Reference-Impact design allowed detection of differential responses to factors such as climate, between control and reference streams. Monitoring data confirmed that prior to SCM installation; the LSC catchment was similar to the degraded control streams, and consistently poorer than the forested reference streams.

Through one lens, the experiment is a step in broader AM, in that it has been informed by past failure of local-scale interventions to effectively restore stream ecosystems degraded by catchment-scale processes (Bernhardt and Palmer, 2011). Within the experiment, AM has been used to compare the effectiveness of competing social engagement approaches and competing SCM designs to reduce delivery of contaminants and physical disturbance to the receiving stream.

The implementation of the SCM interventions took place over 4 years, using three engagement strategies and associated market-based instruments to prioritize and fund interventions (Bos and Brown 2015). SCM designs evolved in response to the property holders' needs, resources available and effectiveness of implemented SCMs in water and contaminant retention. The needs and attitudes of the property holders were assessed through engagement with the project team and targeted surveys (e.g. Brown et al., 2016). The performance of different SCM types were monitored through studies conducted in parallel to the monitoring of the stream ecosystems (e.g. Burns et al. 2016).

Regular review of monitoring data and progress is essential in AM. A review of progress in 2011 (2 years after the first SCMs were implemented), showed that the installed SCMs had intercepted stormwater runoff from about 5 hectares of impervious surfaces. However, during that time, about 5 hectares of new impervious surfaces had been constructed and connected to the stormwater drainage network. Thus project progress was being countered by new developments. This led to new collaborations with a local municipality and the water authority to establish a special planning provision to ensure all new developments met the LSC project's stormwater runoff objectives. These included: minimize frequency of unfiltered runoff, restore volume and pattern of base flows lost through construction of impervious surfaces, ensure contaminant concentrations of filtered flows meet national water quality guidelines, and reduce total run-off volume to pre-urban stream flow volume.

Phosphorus levels in LSC have already decreased to levels similar to reference streams (Total phosphorus median concentrations decreased from 0.07 mg/L to 0.03 mg/L, Walsh et al. 2015; and N and suspended solids have also decreased, C J Walsh unpublished data); no changes in the ecological indicators (e.g. algal biomass, algal or macroinvertebrate assemblage composition) have yet been observed (Walsh et al. 2015). This is not unexpected, as the rate and trajectory of ecological recovery in streams following removal of stressors will likely span multiple years. Nevertheless, the project's ability to transform policy and practice, as well as community awareness and behaviors, illustrate the benefits of AM in practice.

As with the other case studies, stakeholder input was solicited early in the process and restoration plans incorporated those preferences. The alternative models compared in the study were of the performance and acceptance by the community of different approaches to stormwater control, and the effectiveness of alternative engagement approaches. At the catchment-scale, assessing the effectiveness of the achieved stormwater retention in restoring ecological condition in LSC requires continued monitoring. However, rapid responses in water quality and flow regime suggest a trajectory towards restoration.

These early findings have been sufficient to encourage broader adaptive stream and catchment management in the Melbourne region, with Melbourne Water initiating a program of dispersed SCMs in a second catchment (also being monitored for hydrologic and ecological response), testing an alternative governance approach to community engagement in SCM implementation (Prosser et al., 2015). A preliminary conclusion of both studies has been that

finding sufficient harvesting demand to reduce runoff volumes required for restoration (Walsh et al. 2016) is a major challenge using dispersed SCMs.

This challenge presents a major opportunity in the context of climate change in southern Australia, including Melbourne, where precipitation is predicted to decrease (<http://www.climatechangeinaustralia.gov.au/en/climate-projections/future-climate/regional-climate-change-explorer/super-clusters/?current=SSC&tooltip=true&popup=true>; accessed 4/1/2016). While reduced precipitation will have a large impact on runoff in forested catchments, where most of Melbourne's water is currently sourced, the reduction in impervious runoff volumes will be small, leaving stormwater runoff as a major untapped source of urban water supply (Walsh et al, 2012). These studies are thus serving as steps to accelerate AM in integrated water management, leading to the potential for new catchment-scale experiments that aim to concurrently achieve water supply (through stormwater harvesting into main supplies) and stream protection/restoration in urban catchments.

Summary

All three case studies emphasize the importance of stakeholder input early and consistently throughout the decision making process for AM. Stakeholders are defined broadly to include everyone with an interest in the outcome of restoration, a definition particularly evident in the South River and Melbourne cases (Table 1). Stakeholders with regulatory responsibility must weigh the influence and suitability of the conceptual models developed during problem formulation as illustrated by the Stewart Lake case, where regulatory managers

who were trustees of endangered species used AM in lieu of legal action. However, stakeholders of all types influence the problem formation (priority selections) and not only provide input to, but are informed about progression to the desired future condition (Figure 1, Stakeholders panel).

The integration of ecological risk assessment into the AM process was clear for all three cases. The uncertainty of contaminant exposure provided input for the decision analyses (e.g. selenium exposure to endangered razorback suckers, Stewart Lake; multiple contaminants in stormwater runoff, Melbourne) and was balanced with the protection of resources deemed critical for a desired future state (e.g. preservation of old growth trees, South River). Ecological risk assessment also provided input for selecting evaluation criteria and models against which progress toward a desired outcome can be measured (Table 1).

Monitoring efforts played a critical and long term role in the ability to conduct the analyses necessary for the AM plans. For example, monitoring for more than a decade informed Stewart Lake stakeholders that selenium concentrations in water were reducing aspects of exposure, but technology to reduce sediment concentrations was inadequate. On the other hand, newer technologies applied in the Melbourne case provided a testable situation where water quality was improved and natural hydrology mimicked to support a potential return to good ecological condition (Walsh et al., 2016). The Melbourne case also emphasized the value of a landscape perspective as controls were outpaced by new developments that added to nutrient and contaminant discharges.

Monitoring data documented the potential effects of GCC on restoration trajectories (Table 1). The study at Stewart Lake suggests that risk of selenium exposure was a function of lake moisture shaped by snowmelt runoff. Lake moisture could be reduced by an evaporative deficit predicted because of GCC in the future. Hence, data not originally collected to characterize effects of GCC were used for that purpose. At South River and Melbourne, precipitation data can be incorporated into stream flow models to predict future flows and potential contaminant-mobilization and discharge as a result of GCC. Flow and contaminant-mobilization as a result of GCC could change the trajectory towards the desired future condition.

In these case studies, decision analysis formalized the process by which stakeholders arrived at the priorities for the sites, which together constituted the desired future condition toward which the restorations were aimed. Alternative models were developed that describe in mechanistic terms how restoration can influence the system toward the desired future condition. We suggest that including known and anticipated effects of future climate scenarios will make these models more robust and better able to guide restoration actions into the future.

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Table 1. Summary of Adaptive Management in three cases.

Case	Model Alternatives	Evaluation/monitoring needed	Efficacy	Link to GCC
South River	a) Hg remediation via capping and/or excavation of contaminated riverbank soils b) Hg remediation and preservation of old growth trees with equal priority	Hg concentration in surface water, sediment and biota Stakeholder satisfaction through public meetings and response to newsletters Health of trees of 8 in D.B.H. or greater; Cap integrity, vegetative growth (80% cover or greater in cap areas) Public access to river through remediated banks	Bank stability Canopy cover and temperature control Reduced bank erosion and loading of Hg to surface water and sediment	Temperature monitoring demonstrates? Surface water temperature moderation during summer Improved fish habitat / shelter under exposed root structures Improved river bank stability during flood events
Stewart Lake	Fill and Drain timing a) Fill with clean canal water prior to runoff and drain immediately after runoff (used in 2000s); b) Fill with snowmelt runoff and top off with canal water (supports endangered fish and meets remediation strategy simultaneously);	Goal: reduction of sediment bound selenium hazards to fish and wildlife. Monitor: Water column [Se] Sediment [Se] Plankton [Se] Fish [Se]	Aquatic biota uptake declining. Razorback sucker larvae have grown to juvenile size. Stocked bonytail are reproducing. AM scheme not working as quickly as stakeholders	Adequate water levels in lake key to reducing uptake by biota. Reduced runoff causing drier lake conditions will slow the remediation process.

			predicted or desired.	
LSC	The experiment tests; a) alternative model to the dominant approach to urban stream restoration b) alternative models of stakeholder engagement c) alternative technologies for stormwater control	Nutrients, Suspended solids, Benthic algal biomass (chlorophyll a) Diatom assemblage index invertebrate assemblage composition	Nutrients and suspended solids are declining, but no changes yet in ecological indicators. Plan adapted to the increase in impervious surfaces as urbanization increased. Transformation of Policy.	As precipitation decreases, there are further incentives for stormwater harvesting and to use AM in integrated water management

Figure 1. Schematic of Adaptive Management with Ecological Risk Assessment incorporated to reflect the process for restoration of contaminated ecosystems and the need to consider the influence of climate change. Ecological risk assessment of hazards has direct impact on priorities formulation and evaluation criteria. Climate change influences on exposure extent and effects is recognized and also influences criteria used to evaluate priorities that are defined by stakeholders. Though boxes and arrows are used to depict the process, the reader is cautioned that this is a fluid and iterative process where stakeholders, researchers, and resource managers are in constant contact to evaluate best alternatives to achieve the desired future condition.

Adaptive Management/Risk Assessment Framework for Restoration of Contaminated Ecosystems – Iterative Process

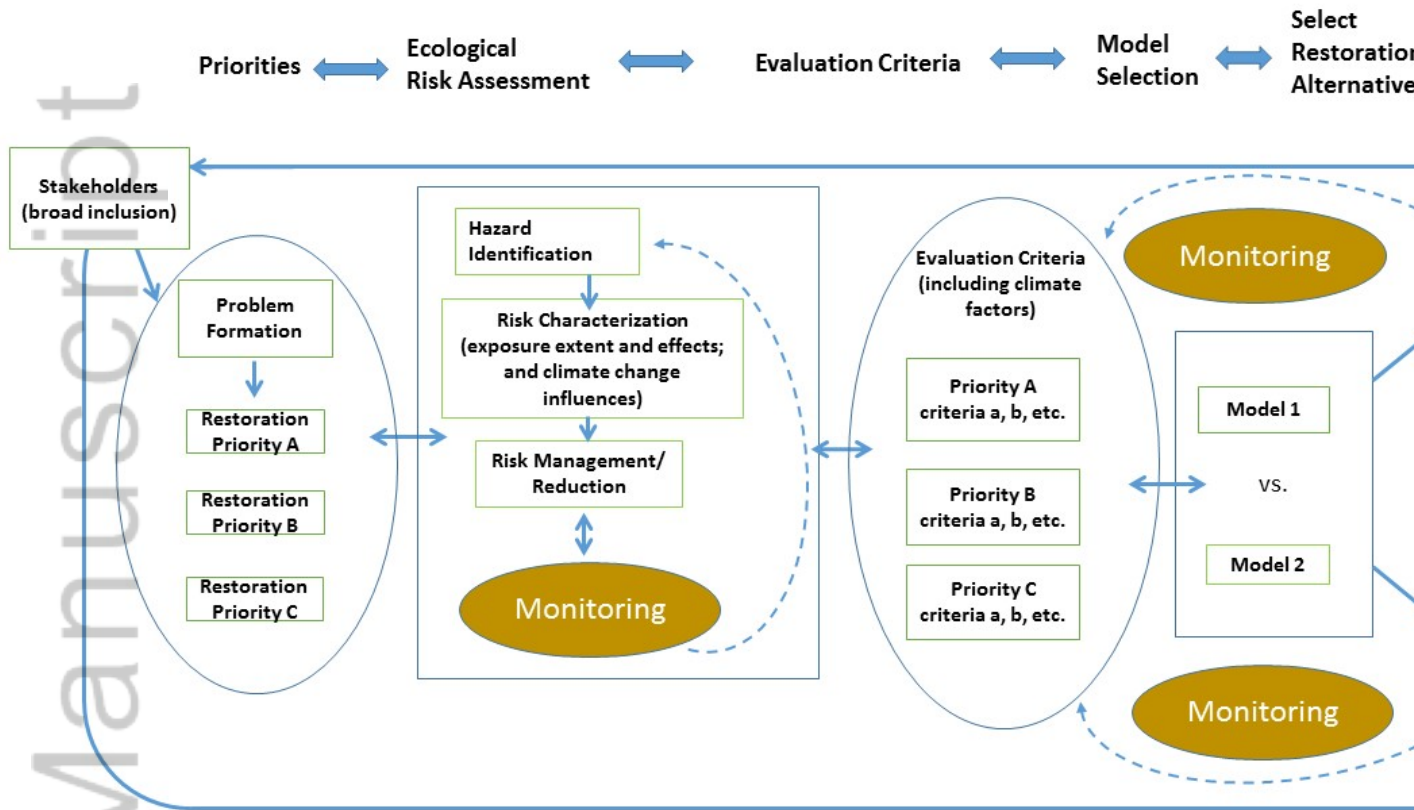
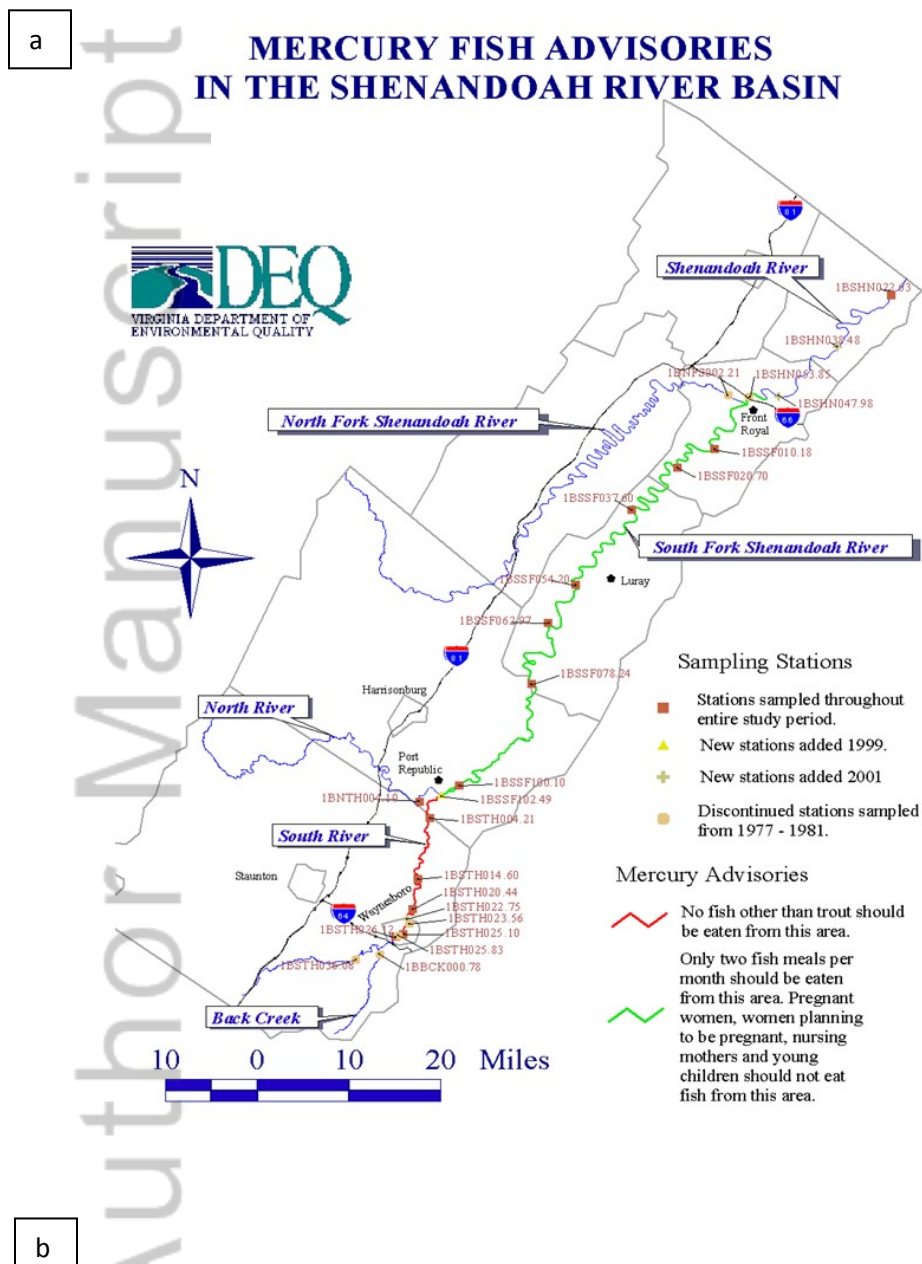


Figure 2. (a) Extent of mercury impacted fisheries, showing location of South River within the Shenandoah River Basin. (b) Alternative models of remediation: the first effectively reduces Hg mobilization into the river, while the second preserves large trees to maintain fish habitat.





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Figure 3. Location of Stewart Lake Waterfowl Management Area, Utah, and drain locations. Pictures in clockwise pattern: Pipeline structure where supplemental water supply enters (top); inlet structure where water from Green River enters Stewart Lake; view from outlet structure of Stewart Lake; fish trap operation and collection at outlet structure.

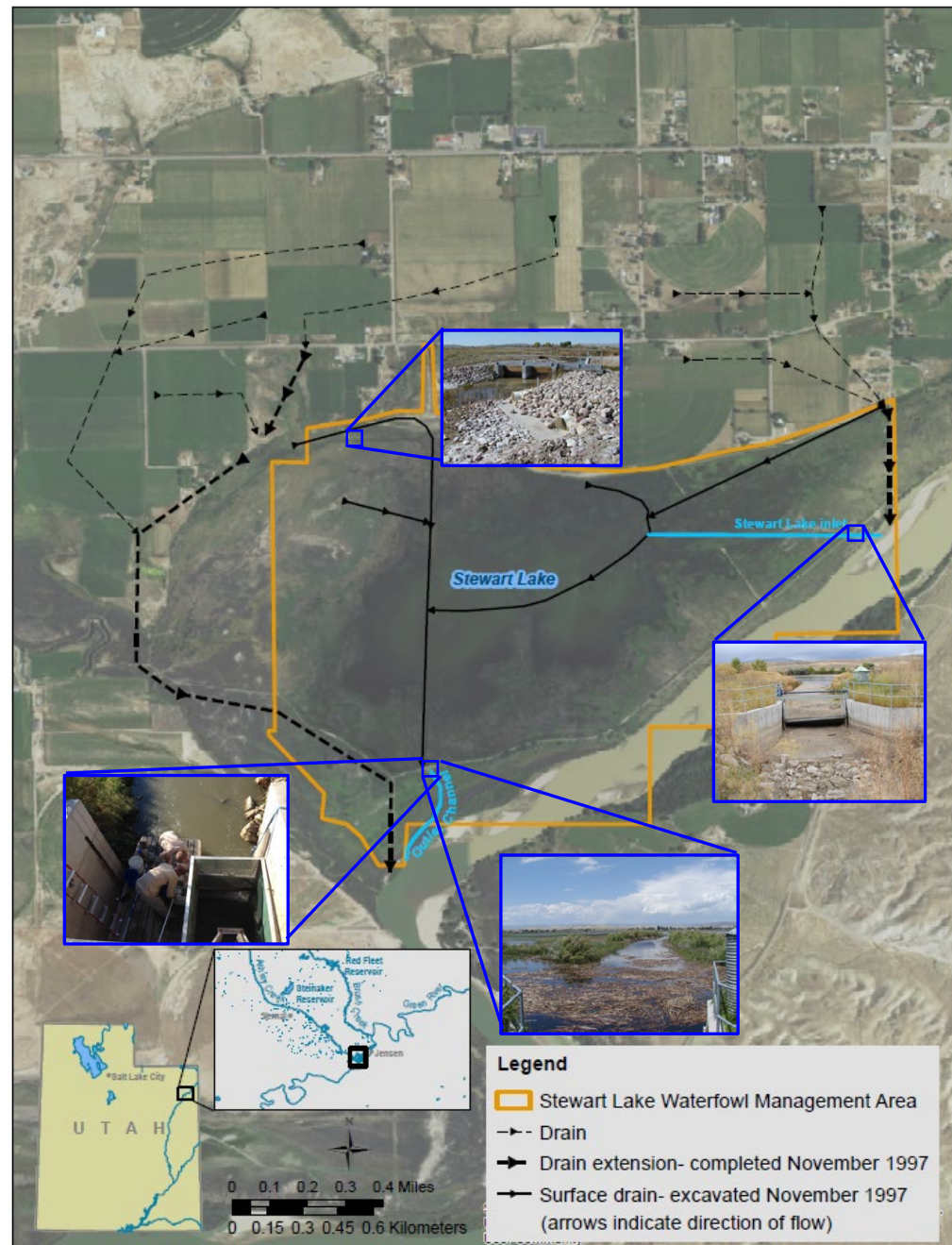
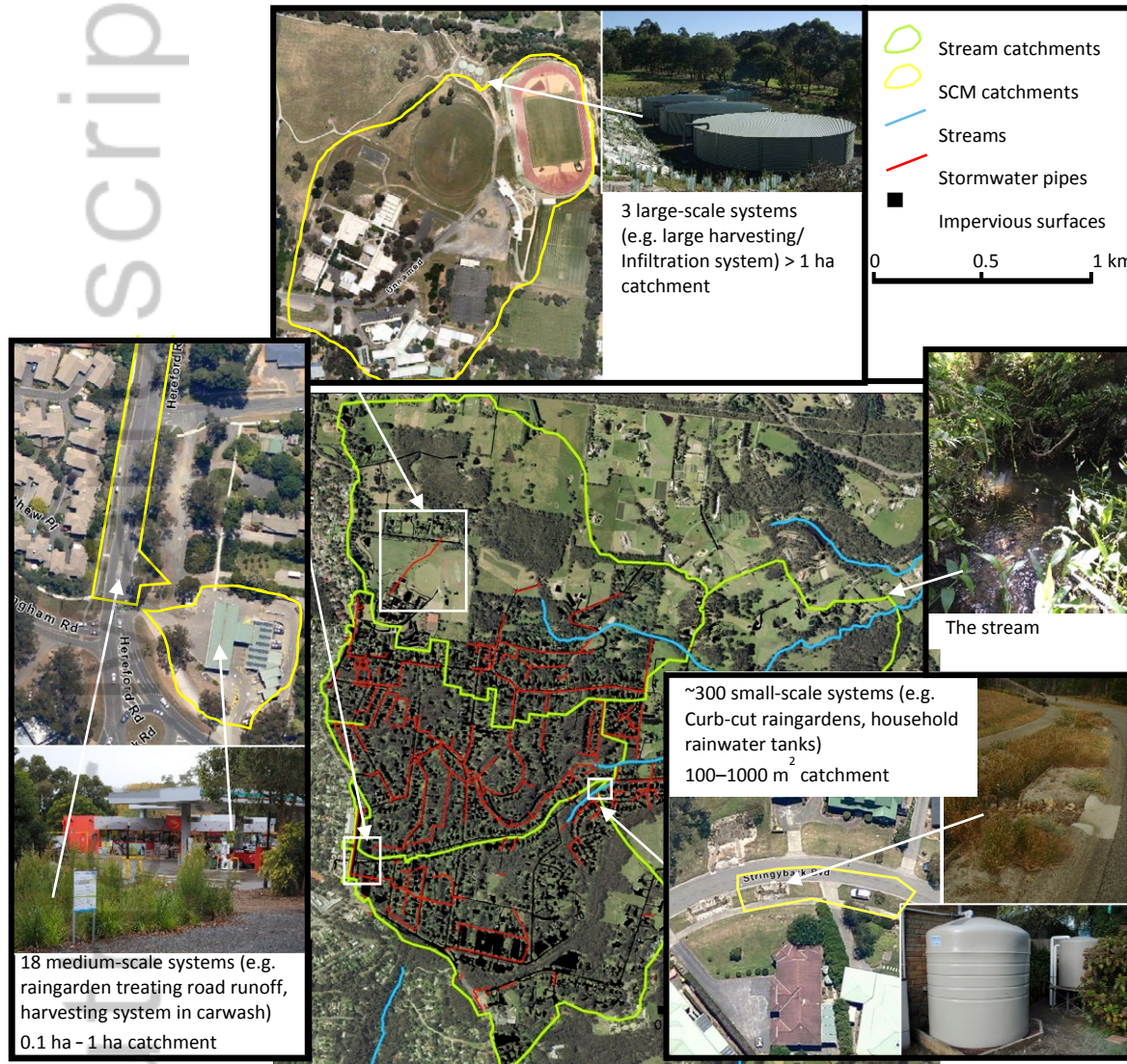


Figure 4. The Little Stringybark Creek catchment, with detailed insets showing the catchments and photos of examples of the stormwater control measures (SCMs) implemented at a range of scales in the catchment, aiming to restore ecological condition of the stream.



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