Restoration and Mitigation Actions
For the Comal Springs Ecosystem

Edwards Aquifer Recovery Implementation Program
December 2009

Prepared by:
Ecosystem Restoration Subcommittee

Submitted to:
Steering Committee of the Edwards Aquifer Recovery Implementation Program

The Edwards Aquifer Recovery Implementation Program (EARIP) is a collaborative stakeholder process, working to develop a plan to protect the federally-listed species potentially affected by the management of the Edwards Aquifer and other related activities. The goals of the plan include contributing to the recovery of these species and producing the Program Documents that will include a Habitat Conservation Plan. The EARIP was created by the Texas Legislature in Senate Bill 3 (2007) and is overseen by a legislative appointed Steering Committee whose members include water utilities, cities, groundwater conservation districts, agricultural users, industrial users, environmental organizations, individuals, river authorities, downstream and coastal communities, and state and federal agencies. Additional information regarding the EARIP can be found at: http://earip.tamu.edu/.

While evaluating the previously created subcommittees that were formed to address specific issues within the EARIP process, the lack of information regarding restoration and mitigation actions was evident. To address this gap, an Ecosystem Restoration Subcommittee was formed to specifically identify and evaluate possible actions.

On May 14, 2009, the EARIP Steering Committee approved the creation of the Ecosystem Restoration Subcommittee and delegated the four charges below.

- To report to the EARIP at its July 9, 2009 meeting regarding the identified opportunities to date for the development of options or potential implementation of the Comal River restoration work by or through the United States Army Corps of Engineers.
- To assess existing conditions and restoration needs for the Comal River. The assessment should specifically identify and evaluate possible restoration actions for the Comal River and include an estimate of the ecological effectiveness and cost of each option.
- To consider opportunities for coordination with and eventual integration of the EARIP process with on-going restoration assessments of restoration options for the San Marcos River.
- To submit its report on restoration options for the Comal and San Marcos rivers to the Steering Committee and EARIP as soon as possible but no later than March 1, 2010.

The Steering Committee appointed as voting members to the Ecosystem Restoration Subcommittee Ken Diehl (SAWS), Melani Howard (City of San Marcos), Chad Norris (TPWD), Nathan Pence (City of New Braunfels), and Todd Votteler (GBRA); and as non-voting members USFWS, USGS, and USACE staff. Members from the non-voting agencies who participated on a regular basis included: Mara Alexander (USFWS), Kevin Connally (USFWS), Patrick Connor (USFWS), Evan Horing (USGS), Catherine Phillips (USFWS), and Jeffery Tripe (USACE). Additionally, Steve Bereyso (SAWS) participated with and contributed to the Subcommittee. At its initial meeting, Nathan Pence was selected as Chair of the Subcommittee and served in that role throughout the duration of the Subcommittee's work.

The Subcommittee identified possible restoration actions through a combination of channels including: review of the 1996 San Marcos and Comal Springs & Associated Aquatic Ecosystems (revised) Recovery Plan, review of the 2003 Draft Comal Springs Ecosystem Management Plan, subcommittee field trips, brainstorming sessions, and soliciting input from the science community, stakeholders, and public. The geographic scope of actions considered included the

contributing and recharge zones of the Edwards Aquifer that we believe potentially affect the Comal Springs ecosystem, the tributaries and watersheds of the Comal Springs ecosystem, all spring runs, Landa Lake, the old and new channels of the Comal River, and the entire Comal River. Actions identified could generally be placed into one of five broad restoration categories:

1. Recreation and Education
2. Bank Stabilization and Riparian Management
3. Dam Alteration and Water Control Structures
4. In-stream Habitat Improvement and Species Management
5. Stormwater Management and Water Quality

Identified actions were assessed for viability and evaluated based on direct benefit to the listed species, contribution to improved water quality, limited negative impacts, estimated cost, increased ecosystem resilience during critical periods, and other related criteria. The Subcommittee developed an informal scoring table (available on EARIP website) which was used internally to help evaluate each restoration action. Final prioritization of the restoration actions as High, Moderate, or Low priority was determined by a vote of the Subcommittee that was then averaged.

Throughout the process, numerous items and actions were identified that require additional research. Many of these research items apply to multiple actions and would be beneficial to the overall management of the Comal Springs ecosystem and EARIP restoration efforts. Additional research items are listed in Appendix I and are intended to be used in the development of future activities and/or the ongoing Adaptive Management Process.

Given the short timeline to meet EARIP goals and funding limitations, the process was abbreviated and largely dependent on existing information. As a result the final report includes no bibliography. However, at the conclusion of the process, members of the Science Community were asked to review the Report Matrix and provide comments. Provided comments were mostly grammatical in nature, and resulted in no significant additions or edits.

The information included in the following report matrix is intended to assist the Steering Committee and EARIP contractors in identifying needed restoration and mitigation actions to be utilized in the development of the program documents.

The final report to the Steering Committee of the EARIP was approved by consensus of all voting members of the Ecosystem Restoration Subcommittee.

	Restoration Action	Issue or Problem Addressed	Priority Ranking	Estimated Cost	Direct Benefit to Species	Potential Negative Impacts and Associated Concerns	Success Measures	Additional Comments
Recreation and Education	Determine current recreational practices and trends that would then be used to develop a Recreation Mgmt Plan that looks at public access points, erosion, vegetative denuding, litter and other recreational impacts.	The impacts of recreation are unquantified, but it is assumed that certain types of recreation in certain areas has impacts.	High to Med	$$	This action has the potential to benefit all endangered species and all other aquatic species. A written document would have to be funded and implemented before being a benefit to the species.	None	Implementation of the measures in the plan and if they achieved the associated objective.	Before a recreation plan can be designed and implemented, research needs to be conducted on the direct and indirect impacts of rec. Establish baseline, geographic scope, and limits. Establishment of what agency or entity has the legal authority to implement the Mgmt Strategies need to be determined before implementation.
	Installation of onsite education through interpretive signs and kiosks in public areas, that address: non-natives, endangered species, litter, access, springs, ecosystem as a whole, etc. Also educational brochures and maps located in city facilities addressing the same.	As a whole, the general public is not educated on the sensitivity of the Comal Ecosystem or the potential negative impacts of their actions.	Med to Low	$$	This action has the potential to benefit all endangered species and all other aquatic species, although impact most likely would be minimal. Education is an indirect benefit at best.	Sign Clutter	Change in park user's behavior.	Limited Educational Signage does exist in Landa Park; provided by EAA and the City of New Braunfels.
	Development of a Citizen Guide to properly functioning riparian zones and activities specific to the Comal River.	The general public is for the most part uneducated about BMP's for Riparian Management.	Med to Low	$$	All Species and Spring Ecosystems. Benefits may be direct or indirect, and most likely minimal.		Change in behavior of citizens.	Nueces River Authority has produced a good example for reference.
	Design of Springfed Pool inlet screen to reduce sedimentation in the pool and exclude biota from entering the pool.	Currently water enters into the Springfed Pool unfiltered, allowing sediment and biota to enter. The more sediment that enters the pool, the more frequent the cleaning of the pool and the associated negative effects with cleaning. Biota that enters the pool becomes trapped in the pool and their survival is unclear at that point.	Med to Low	$$	Fountain darter and aquatic organisms in the old channel. Improve old channel water quality and prevent fountain darters from becoming trapped in the Springfed Pool.	O/M of filter screen	Reduction of streamflow pulses to old channel from cleaning of the Springfed Pool and absence of fountain darters in pool.	There are contractors in NB that have looked at this project previously. Long lasting materials exist in small enough mesh to accomplish.
	Develop and implement a training class for City of New Braunfels seasonal and full-time staff that informs about the endangered species and habitat requirements of all.	Currently City of New Braunfels staff receive no training and for the most part are not educated about endangered species.	Med to Low	$	All species indirectly.	Cost to City to provide training	Educated Staff	

Estimated Cost Legend

$$$$ ≥ $1,000,000
$$$ ≥ $100,000
$$ ≥ $10,000
$ ≥ $1,000

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Bank Stabilization and Riparian Management	Establishment of riparian zones (park, public, private, golf course) - removing non-natives (lugustrum and cane/reed) planting natives, limiting access to reduce trampling, and establish no mow zones.	Current pedestrian traffic causes erosion and loss of natives; resulting in recolonization by non-natives.	High	$$$-$$$$	All species associated with the ecosystem; endangered species and others. Improves water quality of runoff entering system by capturing sediments, reducing pollutants, erosion, and turbidity. Riparian zones also work to increase aquifer recharge and reduce flood intensity.	Limit recreational access to water by the public. Limited visibility of dense vegetation creates security issues.	Amount of acres established and monitoring for success.	Design of this is underway by the City of New Braunfels at Landa Park and Landa Golf Course.
	Establishment of natural bank stabilization and reduced channelization consistent with the overall goals of the EARIP - Landa Lake and Island area.	Severe erosion is occurring in this area.	High to Med	$$$$	All species associated with the ecosystem; endangered species and others.	Future O/M; habitat destruction during construction.	Sedimentation abated.	City of New Braunfels has begun this independently already, is in design phase. Island area is private property.
	Erosion Control on Escarpment just Upstream of Spring Run 3 on Landa Lake, and steep hill along Spring Run 3.	This area is experiencing severe erosion and no preventive measures are in place. Where this water meets Landa Lake is known habitat for the beetles. Also sediment in this area is covering spring openings.	Med	$$$	Protect habitat of beetles that are found along this escarpment . Species that live near the spring openings, or are dependent on pristine water quality.		Installation of erosion control measures.	All property associated with this project is private.
	Establishment of natural bank stabilization and reduced channelization consistent with the overall goals of the EARIP - Landa Golf Course Area.	Severe erosion is occurring in this area.	Med	$$$$	All species associated with the ecosystem; endangered species and others.	Future O/M; habitat destruction during construction.	Sedimentation abated.	City of New Braunfels has begun this independently already, is in design phase.
	Implementation of Turf Establishment and Maintenance Program (native grasses, irrigation, and rotating relief from pedestrian traffic) in Landa Park, Prince Solms, and Hinman Island.	Severe erosion is occurring in this area. Currently pedestrian traffic in these areas denudes turf, especially during drought and hot summer months.	Med to Low	$$$$	All species associated with the ecosystem; endangered species and others.	Possible fertilization and water use.	Establishment of turf and decreased erosion.	City of New Braunfels has begun this independently already, is in design phase.
	Establishment of natural bank stabilization and reduced channelization consistent with the overall goals of the EARIP - Tube Chute Area.	Severe erosion is occurring in this area.	Med to Low	$$$$	The only endangered species would be the fountain darter; all other aquatic organisms in the area would benefit also.	Future O/M; habitat destruction during construction	Sedimentation abated.	Is badly needed, but is outside the distribution of all endangered species except the fountain darter.
	Establishment of natural bank stabilization and reduced channelization consistent with the overall goals of the EARIP - downstream private lands.	Erosion is occurring on private lands downstream of the Tube Chute.	Low	$$$$	The only endangered species would be the fountain darter; all other aquatic organisms in the area would benefit also.	Future O/M; habitat destruction during construction	Sedimentation abated.	Is badly needed, but is outside the distribution of all endangered species except the fountain darter. All on private lands.

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Dam Alteration and Water Control Structures	Manipulation of flows in the old and new channel using the gated culverts to benefit fountain darters and associated habitat in the old channel.	Currently the gated culverts to the old channel are set at a constant flow and never changed. A natural flow regime would be beneficial.	High	$ or $$	Fountain darters benefit because flow component of habitat is adjusted for total springflow, to help maintain spring ambient water quality including water temperature.	Some habitat may not be maintained to protect higher quality habitat.	Completion and implementation of MOU between City of New Braunfels and USFWS.	Draft MOU available; possible flow regime in the 2003 draft Mgmt Plan by Hardy et al. 1999; cost is determining flow regime, keeping gated culverts free of debris, O/M to set flows.
	Manipulation of streamflow at Clemens Dam and tube chute.	Current dam operation is determined by recreational needs, not species needs.	Med to Low	$ or $$	Fountain darter - And all species affected by backwater effect and retention time of Clemens Dam.	Managing for water quality may affect recreation and may increase water recreation impacts.	MOU to manage control structures in Clemens Dam to maintain water quality in river during low river flow.	Especially important during times of low flows. Range of control limited by three gates in Clemens Dam; Trade-off: during moderately low, average and high flows, tube chute operates normally with stage maintained for tube chute, (2) during stressful low flows Clemens Dam's gates are adjusted to lower retention time.
	NBU HydroPlant decommissioning should take into account the endangered species and O/M of the facility should not cause mortality or stress to the endangered species.	Hydroplants through turbine operation, intake, or pass through can cause mortality to fishes.	Low	$$ - $$$	Fountain darter - reduced mortality.			Hydroplant is inactive currently and water passes through.
	Develop a contingency plan that addresses how to proceed should there be a catastrophic dam failure on the Comal River or Landa Lake.	If dam should fail, there is no plan that addresses if or how to replace or rebuild the dam.	Low	$$	All Species.			This has happened on the San Marcos River and it was identified that a plan was needed rather than a decision on-site.
In-Stream Habitat Improvement and Species Management	Plecostomus (*Hypostomus spp* . and *Pterygoplichthys spp* .) and Tilapia (*Oreochromis aureus*) removal - concerted winter effort to remove these non-natives.	Numbers of these two non-natives are growing and both are detrimental to the habitat of all associated endangered species.	High	$-$$	Fountain darter mainly. non-native species compete with native species for resources and alter habitat among other issues. Specifically, tilapia and plecostomus destroy vegetation by consuming it and/or making bare ground nests.	Collection efforts may impact fountain darters or habitat.	Eradication of tilapia and/or plecostomus.	It is common for these tropical non-natives to congregate in spring runs on exceptionally cold days. This includes the Landa Lake spring runs and spring areas in the upstream reach of Landa lake. Areas could be boxed off and fish collected with seines. To be effective, this would require several collection efforts per year over several years and would only reduce numbers, not eradicate invasive species from system.
	Removal of the non-native Asian trematode, *Centrocestus formosanus.*	Gill parasite can cause stress to the fountain darter and eventually mortality.	High	$$ - $$$	Fountain darter.		Eradication of *Centrocestus formosanus.*	Two possible partial but untested control methods are physical removal of *M. tuberculatus* (by dredging) and water turbulence (dams, riffles, and air bubble) to kill drifting *C formosanus* cercaria. Cost determined by method chosen.
	Removal of Ramshorn (*Marisa cornuarietus*) and *Melanoides tuberculatus* snails.	The ramshorn during low flow is a threat to vegetation communities and *Melanoides* is the intermediate host for the gill parasite.	High	$$	Fountain darter. Ramshorn snail removes vegetation that may be used as habitat and *Melanoides tuberculatus* is part of life cycle of parasite that infects fountain darter.	May injure or "take" listed species during removal process.	Eradication of snails.	Requires annual efforts and therefore cost estimate is annual.

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In-Stream Habitat Improvement and Species Management	Elephant Ear (*Xanthosoma sagittifolium* and *Colocasia esculenta*) removal and replacement with native vegetation.	Spread of non-native species is causing a reduction in diversity and loss of natives. Elephant ears also contribute to increased evapotranspiration.	High to Med	$$	All four listed species and other species benefit from removal of elephant ears and establishment of native riparian vegetation that provides woody debris, shade, and habitat.	Temporarily increase of turbidity during removal.	Eradication of elephant ear.	Requires annual efforts and therefore cost estimate is annual.
	Stop or limit aquarium "dump" introductions.	Citizens often dump their entire aquarium into the river when they no longer can keep the aquarium.	High to Med	$$	All species associated with the ecosystem; endangered species and others. Regulating reduces the likelihood non-native or invasive species will be introduced to the system.		No new non-natives introduced to system.	One possible solution is an adopt a pet program like San Marcos has. Enforcement and education are key elements.
	Regulation of bait species used in Landa Lake - coordinating with local bait shops, kiosk signage, and enforcement.	Current practice allows for the use of any live bait species and can result in the introduction of non-natives.	High to Med	$$	All species associated with the ecosystem; endangered species and others by limiting the likelihood non-native or invasive species will be introduced to the system.	Reduces angler numbers.	No new non-natives introduced to system.	Actions could include the prohibition of live bait and allow for use of only artificial; or allow for only the use of native species as live bait. Enforcement and education are key elements.
	Nutria Removal.	Currently in the Landa Lake area Nutria cause erosion, the loss of old growth Cypress Trees along the banks, and destruction of beetle habitat.	Med	$	All species associated with the ecosystem; endangered species and others.	Possible negative PR associated with the killing of any species.	Eradication of Nutria population.	The City of New Braunfels currently has a program in cooperation with Texas Wildlife Services to remove Nutria every winter. However a more ramped up program would be useful.
	Allow fallen trees and coarse woody debris to remain in Landa Lake and the Comal River for the purpose of habitat.	Currently there is pressure to remove all trees and some trees are removed due to human safety concerns.	Med	$	Increases habitat complexity for fountain darter and riffle beetle. Fountain darter benefits from microhabitat alteration (streamflow alteration and structure) while riffle beetle larvae are found on woody debris (not as common as with other species, but still utilized). Also would benefit all other aquatic organisms in the area.	Aesthetic and/or recreational nuisance; Fallen trees can pose a safety threat to recreators.	Policy developed and implemented by the City of New Braunfels mandating trees remain in the water.	Current practices in 2003 management plan. Trees are currently removed based on human safety needs.
	Implementation of a Terrestrial Landscape and Green Waste Disposal Program: including increased enforcement, leave floating debris alone, shake out by hand to dislodge darters, and minimize vegetation put in system by private citizens (i.e. lawn clippings, etc.).	Some citizens currently use the Comal River and Landa Lake for disposal of household green waste.	Med	$	Primarily benefits fountain darter by minimizing take of individuals in debris.	Continual maintenance.	No darters taken by removal of debris.	Island area of Landa Lake should be focus and is private property. It is not uncommon for landowners to dispose of lawn clippings and other green waste by dumping into Landa Lake and the Comal River. Education and enforcement are key elements.
	Removal of Hyacinth, Hydrilla, and Hygrophila; replacing with natives.	Spread of non-native species is causing a reduction in diversity and loss of natives.	Med	$$	Removal of non-natives and reestablishment of native vegetation should create more usable and ideal habitat for the fountain darter.	May injure or "take" fountain darters during removal process.	Eradication of Hyacinth, Hydrilla, and Hygrophila	Requires annual efforts and therefore cost estimate is annual.

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Stormwater Management and Water Quality	Implementation of best management practices to address stormwater runoff in and around Landa Lake; could include stormwater retention ponds, rain gardens, wetlands, and storm sewer filters.	During rain events, surface runoff enters directly in to Landa Lake and the spring runs without filtration or settling.	High	$$$	All species. Water quality concerns from direct runoff can threaten endangered species habitat or if severe enough cause direct mortality.	Possible loss of usable park space.	Installation.	Expand efforts beyond TPDES and MS4 requirements. Hard to quantify positive effects.
	Increased prohibition of hazardous materials routes that cross the Comal River, watershed, or associated tributaries.	Roads that cross the Comal and recharge zone are not identified hazardous materials routes, but hazardous materials are allowed to cross. A spill could be catastrophic depending on location.	High	$ or $$	All species associated with the ecosystem; endangered species and others.	Could cause inconvenience through less direct routes.	No massive kill due to hazardous materials spill reaching the Comal Ecosystem.	Work with TXDoT, County, City of New Braunfels, and state agencies to establish restricted zones; cost is to install signage and designate alternative routes; City of New Braunfels has existing hazardous materials response plan.
	Development of household hazardous materials collection program and increased awareness about discarding household hazardous materials (including pharmaceuticals).	Often hazardous materials are discarded by pouring on the ground or in a storm sewer.	High	$ or $$	All species associated with the ecosystem; endangered species and others.		Receiving hazardous materials through program.	Work with state and local agencies to establish; City of New Braunfels does currently have a limited program and will increase as part of their upcoming MS4 compliance; cost is to establish a drop center and publicize.
	Implement an aerobic and anaerobic septic system registration, evaluation, and permitting program to prevent subsurface pollutant loadings from potentially being introduced to the spring ecosystem.	Potential leaking underground septic systems leaching nutrients (i.e. nitrates) and other constituents of concern into the springs ecosystem via groundwater transport pathways.	High	$ or $$$$	All Species and spring ecosystems.	Cost for cities to fully implement; politically challenging to determine what systems need to be upgraded.	All septic systems reevaluated and brought into TCEQ compliance with accepted best-maintenance standards with no new non-compliant systems installed.	The cost to identify, monitor, and impose construction specifications and retrofit standards for new and existing septic systems is relatively low. City Ordinances and Codes could be implemented to require the appropriate provisions. Costs to install new systems, or upgrade existing systems, could be seen to be onerous if it falls upon a single entity (i.e. a homeowner). Cost-assistance measures could be developed.
	Land acquisition throughout the watershed and recharge and contributing zones for conservation and green space; acquired land should fit the overall goals of the EARIP.	Land in the watershed, around Comal Springs, and the Comal River is being developed as pieces become available for acquisition. With no acquisition program, there will be minimal green space around the river or in the watershed.	High	$$$$	Depending on where conservation easement is located, could be direct or indirect impact to all species; endangered species and others.		Improved water quality and preserved green space.	Property could be above Landa Lake and Springs, at the Lake, or in the upstream watershed of Blieders Creek. Could also include development rights and conservation easements throughout the recharge and contributing zones.
	Conversion of impervious cover to pervious cover.	Impervious cover reduces aquifer recharge and contributes to stormwater pollution.	High	$$$$	All Species and spring ecosystems.	Loss of usable roads, extra expense during development.	Implementation of development codes that require conservation easements in lieu of development or require development to be no more than X% impervious.	One solution is watershed wide development restrictions and requirements.

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Stormwater Management and Water Quality	Restoration of riparian zones along tributaries (Blieders, Panther, Dry Comal) and entire watershed, including removing non-natives, planting native vegetation, bank stabilization, and possible wetland creation.	During runoff events the watershed and tributaries contribute to poor water quality in Landa Lake and the Comal River.	High	$$$	All species associated with the ecosystem; endangered species and others. Improves water quality from tributaries, Reduce runoff and erosion from tributaries as well as siltation and turbidity in Landa Lake associated with rainfall events.	private landowner cooperation required.	amount of riparian or wetland habitat created; water quality monitoring pre and post.	Primarily Private Lands. Priority should be focused on areas that contribute significantly to water quality concerns or areas closest to Landa Lake.
	Establishment of Aggressive and Frequent Water Quality Monitoring (surface and ground) that considers location, time of day, day of week, time of year, and all water quality parameters.	Efforts to monitor water quality around Landa Lake and the Comal Springs are minimal at best.	High	$$$	All species; endangered species and others. Can prevent future water quality problems by detecting early warning signs. Also useful in building baseline conditions.	None.	Success is preventative, there may be no direct measure.	Current sampling is per Clean Rivers Program, need to expand the frequency and scope.
	To evaluate and implement watershed wide regulations aimed at following Extension Service guidelines for pesticide, herbicide, and fertilizer applications. Environmentally safe alternatives could be used in order to reduce the potential of and/or prevent pollutant loadings from being introduced to the spring ecosystems.	Chemical applications leach into groundwater and/or storm water run-off being introduced to the spring ecosystems.	Med	$$	All species and spring ecosystems.	The cost to indentify monitor, educate and impose regulations that would require only organic compounds under certain conditions is a low cost.	Community embraces the concept and promotes all applications to be environmentally friendly. And an educational program or material is provided.	Organic alternatives should be considered. Refer to the U.S. Environmental Protection Agency (EPA) for alternatives.
	To evaluate and implement a program that would adhere to local City Codes and State regulations to reduce and/or prevent the potential for subsurface pollutant loadings from being introduced to the Spring Ecosystems through abandoned well systems.	Addressing the potential pollutant contamination of groundwater via a direct conduit through abandoned wells, which could adversely impact the springs ecosystem. Citizens often used abandoned wells as a way of disposing of hazardous materials.	Med	$$$	All species and spring ecosystems.	Limited number of locations - capping and registering all wells that could be a direct conduit to the water flowing to the springs is important.	All identified wells in a defined area have been registered, and if not approved for use are properly plugged or capped.	Spring communities may consider designating staff members to comply with State plugging regulations of abandoned wells. Potential for cooperative training and information sharing - both San Antonio and EAA have a program that consists of registering, inspecting and plugging wells if deemed appropriate. Partnering with or enforcement of TCEQ Regulations may be one solution.
	Prohibition of construction materials (dirt or mulch) storage in Landa Park or Landa Golf Course.	Piles of dirt and mulch stored in these areas washes in during rain events.	Med	$	All species associated with the ecosystem; endangered species and others.	None.	Create City of New Braunfels policy to prohibit construction materials to be stored in Landa Park	City of New Braunfels staff is currently working on establishing an internal City policy preventing.
	Evaluate current procedure and increase frequency or impose more stringent requirements on the construction and monitoring of NBU owned sanitary sewer mains in the vicinity of springs ecosystems.	Reduce or eliminate pollutant loadings from entering the Spring Ecosystems through leaking or poorly installed sanitary sewer mains.	Med	$$	All species and spring ecosystems.	CMOM program is moderately costly - repair and replacement of improperly installed or leaking infrastructure.	Capacity Management Operation and Maintenance Program implemented in vicinity of spring habitats.	Focus on areas closest to the springs.

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Stormwater Management and Water Quality	Conversion of impervious cover (roads, driveways, and rooftops) to pervious in public areas. Including no vehicular traffic or roads in Landa Park.	Impervious cover reduces aquifer recharge and contributes to stormwater pollution. Vehicles and roadways combined represent a direct pathway for pollutants to waterways during rain events.	Med	$$	All species; endangered species and others. Decreases input of sediment and other pollutants, also decreases rate and quantity of stormwater inflow.	None.	Measure water quality parameters before and after the implementation of these measures.	
	Installation of detention ponds, water quality measures, and riparian zones at the local Rock quarry operations and plant operations; possible consideration of stormwater and tributary filtration	Water quality impairments could be a result of runoff from these facilities.	Med to Low	$$$$	All species associated with the ecosystem; endangered species and others	Cost to quarries.	Implementation of measures.	Very little is known about this action; although it is generally agreed that this should be pursued as it could prove to be very significant.
	Prohibition of feeding all species in Landa Park.	Unnaturally large numbers of wildlife created by concentrated feeding can cause excessive buildup of feces; thus contributing to nutrient loading, ecoli concerns, D.O. fluctuations, and algae buildup.	Med to Low	$	Indirect benefit, omnivorous waterbirds may impact submergent plants.	None	Absence of non-native and nuisance waterbirds.	Non-native waterbirds should be excluded from Comal Springs invertebrate critical habitat; water quality impacts from waterbirds including nutrients are eliminated. Pay special attention to feral and non-native species.
	Evaluate current SOP's established by USFWS at the golf course in Landa Park. May include refinement and/or initiation of BMP's for turf which should include pesticide, fertilizer and irrigation water applications. Should identify the most environmentally-beneficial practices addressing over applications of fertilizers, irrigation waters and pesticides. One alternative could be to relocate golf course.	Golf course nutrient and pesticide stormwater run-off and groundwater has potential to leach into springs ecosystem via groundwater transport.	Med to Low	$$$	All species and spring ecosystems.	Portions of the golf course may have to be modified to provide buffers, and mitigate for ongoing operation of the course in a less-impactful manner.	Stormwater quality runoff is improved and buffers are provided that increase habitat quality for aquatic ecosystems.	One alternative could be to relocate the golf course. If the golf course is not relocated, the goal would be to protect the quality of run-off water and leachate to the Comal springs area; minimize erosion and transport of soil resulting from golf course activities and preserve and protect native plant and wildlife habitats to the greatest extent practicable. Development of an environmental management plan which should consist of the climate, irrigation, soils, geology, water resources, turf grass, and vegetation conditions at the golf course should be taken into consideration. Identify turf grass, soil, water quality risks an the development and implementation of an. If appropriate, identify specific alternate management practices and current Best Management Practices ("BMP's") for controlling runoff, site modifications, environmentally sound irrigation, soil and water conservation, fertilization and pest and disease control.
	To evaluate and implement a watershed wide program that could eliminate coal tar applications on roads that would reduce polycyclic aromatic hydrocarbons (PAH's) from entering the Spring Ecosystems.	Coal tar and Polycyclic Aromatic Hydrocarbons (PAH's) from roadway's enter the spring ecosystems and adversely impact the benthic ecosystem community.	Med to Low	$$	All species and spring ecosystems.	Should not be too controversial, secondary used park roads and walkways need not be asphalt, some sort of impervious cover could be used.	Other source pavement types such as crushed granite be utilized in close proximity to waterways and springs.	Recent studies by the USGS' National Water Quality Assessment have identified seal coating, which is the black, shiny surface often applied to asphalt pavement, as a significant and previously unrecognized source of extremely elevated concentrations of PAH's in streams. In one instance, runoff from parking lots sealed with a type of coal tar-based sealant had PAH concentrations of 65 times higher than concentrations from unsealed parking lots. PAH's are suspected human carcinogens and are toxic to aquatic life. Biological studies conducted by the City of Austin found a loss of species and decreased numbers of organisms at the PAH concentrations seen in Austin streams. Officials observed these effects at sites downstream from the points where sealed parking lot runoff enters the streams.

	Restoration Action	Issue or Problem Addressed	Priority Ranking	Estimated Cost	Direct Benefit to Species	Potential Negative Impacts and Associated Concerns	Success Measures	Additional Comments
Stormwater Management and Water Quality	Evaluate current SOP's recommended by the USFWS for the Springfed and Olympic Pool O/M; Update as needed for benefit of endangered species.	Current O/M uses small amounts of chemicals and neutralizers that eventually end up in the old channel of the Comal; current O/M also creates a weekly pulse in the old channel.	Med to Low	$	The only endangered species would be the fountain darter; all other aquatic organisms in the area would benefit also.	Use of small amounts of chemicals and water pulses.		There is the opportunity to evaluate the O/M form a habitat mgmt strategy: pulses, water flow, regime, etc. The City of New Braunfels currently follows USFWS recommendations from the 2003 Draft Comal Mgmt Plan.
	Installation of erosion and water quality BMP's on the old channel Schlitterbahn parking lot, including riparian and vegetative buffer zones. One alternative could be to relocate the parking lot.	All Schlitterbahn employees park on a gravel parking lot next to the old channel of the Comal River. Fluids and pollutants from the cars can directly enter the old channel.	Med to Low	$$$	The only endangered species would be the fountain darter; all other aquatic organisms in the area would benefit also.		Installation of any measures	Is on Schlitterbahn property.
	To evaluate and implement local City Codes or ordinances to control and/or eliminate domesticated pet-waste-induced bacterial loadings from entering the spring ecosystems.	To control and/or eliminate the bacterial loadings from entering the Spring Ecosystems via storm water run-off from pet waste. This waste contributes to nutrient loading and possible D.O. crashes.	Med to Low	$	All species and spring ecosystems.	The cost to educate, provide plastic bags, and signs along with the development of a City Ordinance is relative low.	Community embraces the concept and utilizes the Dog waste cleanup, construction of a designated Dog park with dedicated maintenance.	Dog waste often contains a variety of organisms, including bacteria and internal parasites, both of which may be communicable and harmful to humans, especially children. Fecal coli form bacteria, for example, can cause severe stomach illness and rashes. There also maybe a consideration of specifically designating a "Dog Park" area and no dogs are allowed outside this area. Currently there are pet waste stations in Landa Park.
	Relocation or upgrade of the railroad trestles over the new channel of the Comal River, for the purpose of minimizing habitat impacts from trestle, preventing hazardous material spills, and increasing the safety of railroad operations over Comal River.	Creosote bridge structure or spill from railroad can pollute the River.	Low	$$ or $$$	Fountain darter habitat would be less likely to receive pollution through rail accident. Also helps associated plants and invertebrates.	Some habitat disruption during construction.	Existence of railroad trestle that completely spans river; maximize safety of operations near and over Comal River; trestles over new and old channel currently are creosote treated timbers.	Union Pacific has replaced two trestles over San Marcos River.
	Litter removal from Landa Lake and islands.	Litter from stormwater events and the wind is currently allowed to collect in Landa Lake with limited removal.	Low	$$	All species associated with the ecosystem; endangered species and others.	Disturbance of habitat during collection of litter; or destruction of habitat.	Removal of all litter.	There are numerous contractors and companies that can perform this service.
	Installation of hot ash boxes in areas of public grilling throughout the parks system.	Ashes end up in the waterways and contribute to nutrient loading and turbidity.	Low	$	All species; endangered species and others. Increases water quality by containing charcoal remains.	Could increase/encourage the use of grills in the parks.	Reduced amount of charcoal emptied onto the ground.	

Appendix I

Additional Research Needed for Restoration of the Comal Ecosystem
Possible Components of the Adaptive Management Plan

Recreation and Education

- A determination of which agencies and entities have the authority to conduct activities or impose restrictions on the Comal River. This information will be important as the EARIP works to implement management strategies and restoration activities.

- Determine recreational baseline on Landa Lake, the old channel, the new channel, and the Comal River that includes, but is not limited to: user numbers, impacts to riparian and aquatic vegetation, impacts to the listed species and their associated habitats, geographical and spatial analysis, recreation types, seasonal and annual variations, and effects of varying springflows. This information could be used to develop and implement management strategies as relates to recreation.

- Revisit the management strategies recommended by USFWS (2003 Draft Comal Management Plan) and currently used by the City of New Braunfels in relation to the operation of the Springfed Pool in Landa Park. Looking specifically at updating procedures to develop management strategies that promote habitat for Fountain Darters and improve water quality.

Bank Stabilization and Riparian Management

No research items were identified in this category. Although many of the other identified research items apply indirectly.

Dam Alteration and Water Control Structures

- Research impacts associated with a catastrophic dam failure on the Comal River. Plan should address questions such as: should the dam be fixed, what are the potential impacts to the threatened and endangered species and what to do with species to ameliorate impacts.

- Identify appropriate flow regime to maximize fountain darter habitat in the old channel of Comal River.

In-stream Habitat Improvement and Species Management

- Determine areas on the Comal River and in Landa Lake that have experienced heavy sedimentation; and determine positive effects or potential concerns from dredging those identified locations. Could be done in conjunction with dredging for snail removal.

- Monitoring and modeling of *Centrocestus formosanus*, an exotic fish gill parasite, in the Comal River. Correlations among spring flow, *Melanoides tuberculatus* (snail host of *C. formosanus)* numbers, and parasite numbers need to be established. Determination of correlations among flow, snail host, parasite, and fountain darter will permit the development of a model to predict future effects of the parasite on fountain darter survival.

- Management of *Centrocestus formosanus*, an exotic fish gill parasite, in the Comal River. Elimination of the parasite from the rivers is not likely. Physical removal of the parasite's host snail, *Melanoides tuberculatus*, by dredging and using turbulence (dams, riffles, and air bubbles) to kill drifting parasites are possible methods to manage the effects of the parasite on the fountain darter. Removal of snails by dredging could be done in conjunction with sediment removal.

- Monitoring and modeling of the effects of cumulative spring discharge on the fountain darter and Comal Springs riffle beetle populations in the Comal River need to be determined. Also, the effects of the proposed springflow regime on the listed species needs to be monitored, evaluated, and a predictive model developed accordingly.

- Monitoring of the Comal River to detect newly introduced species before they become problematic needs to be conducted. Bi-annual surveys of the plants, invertebrates, and fishes should be done to identify newly introduced species and to determine if significant changes in native species have occurred. Non-native species need to be removed immediately. Causes of significant changes in native species numbers or distributions need to be determined and addressed.

- Determination of the best methods to remove non-native, such as plecostomus, tilapia, giant cane, elephant ear, ramshorn, melanoides, and others.

- Determine effects of introduced non-native species from all sources: live bait, aquarium dumps, storm events, etc.

- Determination of all life history characteristics of the endangered invertebrate species associated with the Comal Springs ecosystem. This should include the endangered species, karst species, and the undescribed species of salamander.

- Survey pertinent springs in the region for the purpose of identifying new locations and populations of the endangered species. These efforts could also focus on the karts species and undescribed species of salamander.

Stormwater Management and Water Quality

- Design and implement an aggressive water quality and quantity monitoring program on Landa Lake, the Comal River, and associated tributaries. Taking into account differences between days of the week, stormwater events, metals and PAH's, nutrient loading,

turbidity, seasonal variations, springflow effects, point source discharge effects (golf course), etc.

- Determination of hydrologic features and flow paths; especially major conduits and recharge features that relate to Comal Springs. This information could be used to determine priority of which recharge areas to protect first, relocation of hazardous material routes away from direct recharge areas, and development decisions.

- Evaluate management strategies and current practices used by the City of New Braunfels in relation to the operation of the golf course. Implementation of an aggressive water quality monitoring of leachate and stormwater runoff to determine the quality of the water potentially leaving the site and entering the spring system via groundwater and/or stormwater run-off. Monitoring efforts could include analysis of plant tissue, soil, and irrigation water, as well as pesticide and nutrient applications to develop management strategies that promote habitat for fountain darters and improve water quality.

- Determination and location of abandoned water wells. This information could be used to enforce the capping of these wells but should also determine priority based on proximity to spring openings and direct recharge conduits.

- Establish effects, if any, caused by the presence of *Thompsodinium*, the dinoflagellate plume discovered in the Blieders Creek area of the Comal River during the summer of 2009.

- Evaluation of need and feasibility of a real time flow gauge on Landa Lake above Spring Run 3. This gauge could be used to establish flows and water quality during storm events and to determine the contribution from springs in the upper end of Landa Lake during normal and low flow periods.

- Identify leaking aerobic and anaerobic septic systems in the vicinity of Landa Lake and the recharge and contributing zones of the Edwards Aquifer. This information would also be useful in prioritization of which septic systems to address first. Determine if a more aggressive program is needed.

- Determine effects to the Comal Springs ecosystem caused by local rock quarries and cement plants. Develop and design BMP's to mitigate.

- Evaluate the existing CMOM program and upgrade if needed.

Report on Restoration Options for the San Marcos River

The San Marcos River (River) is home to six federally protected species. The River has many invasive plant and animal species that compete with and disrupt the habitat for the River's native species. The growing human population within the watershed is also constantly changing the River (e.g., pollution, sedimentation, the building of dams, etc.). This report on restoration options (in tabular form) for the River includes pursuits to restore every aspect of the River, comprising: activities that enhance value, use, appearance, access, safety, and knowledge; practices designed to reduce/eliminate erosion or slumping of bank material into the river channel; alteration of dams to reduce negative ecological impacts; removal of barriers to upstream/downstream migration of fishes, including the physical removal of barriers and also construction of alternative pathways; altering structural complexity to increase habitat availability and diversity for target organisms and provisions of breeding habitat and refugia from disturbances and predation; practices that directly alter aquatic native species distribution and abundance through the addition or translocation of animal and plant species and removal of exotics; revegetation of riparian zone and removal of exotic species; and flow modifications that include the construction and management of structures (ponds, wetlands, and flow regulators) in urban areas to modify the release of storm run-off into waterways.

In order to put together such a comprehensive report, a team of experts, stakeholders, and all interested parties joined together. Representatives from state agencies, federal agencies, local government, landowners, NGOs, and multiple Texas universities have been attending each meeting. We worked together to create a report that encompasses all goals and objectives for the future of the river. The restoration actions we recommend are broken into five main goals/categories:

1. Aesthetics/Recreation/Education
2. Bank Stabilization and Riparian Management
3. Dam Alteration and Aquatic Organism Passage
4. In-stream Habitat Improvement and Species Management
5. Stormwater Management

All actions identified were given a priority level (H = High, MH = Moderate to High, M = Moderate, LM = Low to Moderate, and L = Low) and an estimate of cost ($ = < $10,000, $$ = $10,000 - $100,000, $$$ = $100,000 - $1 million, $$$$ = >$1 million); both decided by majority vote. The geographic scope of actions considered included the San Marcos River from the headwaters in Spring Lake down to the first low water crossing after the confluence with the Blanco River, and the entire watershed that surrounds this portion of the river and its tributaries.

The report matrix is followed by a glossary which describes in more detail what each restoration action item entails.

While creating the matrix, we found that some of the action items we suggest would benefit from research projects done prior to the described actions. Many of these research topics apply to multiple actions and would be beneficial to the overall management of the San Marcos River restoration efforts. These research items are listed in Appendix I and are intended to be used in the development of future activities and/or the ongoing adaptive management process. As in the report matrix, we also gave each research question a priority level (following the same designations as described above) and an estimate of cost (following the same designations as described above); both decided by majority vote.

The information included in the following report is intended to assist the EARIP Steering Committee and contractors in identifying needed restoration and mitigation actions to be utilized in the development of the program documents.

Restoration Plan Goal	Restoration Action	Issue or Problem Addressed	Priority Ranking	Estimated Cost	Species Benefited	Potential Negative Impacts Associated	Success Measures	Additional Comments
1	Develop educational publications	Educate river-users on the importance of the river ecosystem and ways to protect it including the negative impacts of invasive species	**MH**	**$**	All	None	Less polluting and releasing invasive species into the river	
1	Develop an internet presence to market existing and upcoming educational materials	Educate river-users on the importance of the river ecosystem and ways to protect it including the negative impacts of invasive species	**M**	**$**	All	None	Less polluting and releasing invasive species into the river	
1	Develop travelling exhibits and demonstration sites	Educate river-users on the importance of the river ecosystem and ways to protect it including the negative impacts of invasive species	**LM**	**$**	All	None	Less polluting and releasing invasive species into the river	
1	Increase enforcement of park/city rules re: polluting and aquarium dumping	Trash in the river and invasive species introductions	**H**	**$$**	All	None	Less polluting and releasing invasive species into the river	
1	Remove Floating debris from Texas wild-rice stands	Trash in the river, low light levels and inhibition of flowering for Texas wild-rice	**H**	**$**	Texas wild-rice	None	Larger Texas wild-rice stands with a higher percent cover	

1	Relocate Texas State University watercraft classes to Spring Lake	Texas wild-rice damage	**M**	**$**	Texas wild-rice	None	Less damage to Texas wild-rice stands from watercraft	
2	Create pre-determined access points into the river	Unstabilized banks	**H**	**$$$**	All	None	Less sedimentation in the river, better riparian buffer zones, less trampling of native aquatic vegetation	$$$ is assuming construction material will be needed (i.e. stacked rock, pathways, etc.)
2	Create non-access points in sensitive areas	Unstabilized banks and trampling of native aquatic vegetation	**H**	$$	All	None	Less sedimentation in the river, better riparian buffer zones, less trampling of native aquatic vegetation	Non-access points = bank stabilization using prohibitive (thorny) plants
2	In-stream barriers as needed to protect habitat	Protection of endangered species from trampling	**M**	**$$**	All	Flooding could move barriers to undesired locations	An increase in endangered species population counts in the fenced-off areas	
2	Involve riverside landowners in riparian management	Buffer zones, pollution, invasive species	**MH**	**$**	All	None	Adequate buffer zones, less pollution and invasive species in the river	
2	Remove elephant ear from the river	Invasive species competition with native plants	**M**	**$$**	Texas wild-rice	Bank destabilization	Less elephant ear in the river and more native river-edge species	Has to include planting natives in its place for bank stabilization
2	Remove invasive trees from the river's riparian zone	Invasive species competition with native plants	**M**	**$$**	Terrestrial vegetation and animals	None	Less invasive species along banks of the river	These two actions items need to be done together
2	Reintroduce native riparian vegetation	Invasive species competition with native plants	**MH**	**$$**	Terrestrial vegetation and animals	None	Less invasive species along banks of the river	

2	Prune riparian vegetation	Watercraft movement being pushed over Texas wild-rice stands	**L**	**$**	Texas wild-rice	None	Less damage to Texas wild-rice stands from watercraft and more robust stands (higher percent cover) under pruned areas	This needs to be approved by authorized state and/or federal agencies per pruning event
2	Relocate coarse woody debris (CWD) from areas immediately upstream of Texas wild-rice	CWD scours Texas wild-rice plants out of the river during flooding events	**M**	**$**	Texas wild-rice	Loss of fish and invertebrate habitat	No scouring of Texas wild-rice stands during flooding events	Only **DIRECT** threats to Texas wild-rice
2	Create a buffer zone along the river's edge and tributaries where possible	Runoff, pollution and sedimentation	**H**	**$$**	All	None	Less pollution and sedimentation in the river.	
3	Create Fish Passage Structures in Spring lake Dam and Rio Vista Dam	Natural migration patterns of fish in the river are currently obstructed	**M**	**$$$$**	Fountain darters and potentially all spp. due to return of natural conditions	None	Higher genetic flow between sections of the river for fountain darters and return of American Eel and Macrobrachium	
3	Create an emergency plan for the possible case of dam failure	Sudden loss of habitat for Texas wild-rice and other native aquatic vegetation	**H**	**$**	Texas wild-rice	None	The saving of Texas wild-rice stands in times of sudden dam failure	
3	Cummings Dam and Capes Dam alteration	Texas wild-rice and fountain darter limited habitat availability	**M**	**$$$$**	Potentially Texas wild-rice and fountain darters	Research needed (see below)	Dam alteration allowing for an increase in potential Texas wild-rice and fountain darter habitat	Research needed prior
3	Create/Fulfill a landscaping plan if dam alteration will be put forward	Bank stabilization and fulfilling landowners needs for access for cattle and recreation.	**M**	**$$**	Potentially Texas wild-rice and fountain darters	None	Dam alteration allowing for an increase in potential Texas wild-rice and fountain darter habitat	Research needed prior

4	Annual monitoring of in-stream biota	Not knowing when and where species are changing (in terms of presence or coverage) within the river	**H**	**$$**	All	None	Understanding of aquatic ecosystem trends	Estimated cost is per year
4	Remove invasive plant species that negatively affect native species	Non-native species out-competing native species in the river for space and resources	**H**	**$$$**	All	None	Higher population numbers for all native species including all federally-listed species	This most likely will be an on-going process- but needs a big jump start. These two actions need to be done together.
4	Reintroduce native aquatic plants	Non-native species out-competing native species in the river for space and resources	**H**	**$$**	All	None	Higher population numbers for all native species including all federally-listed species	
4	Remove invasive animal species that negatively affect native species	Non-native species out-competing native species in the river for space and resources	**H**	**$$$**	All	None	Higher population numbers for all native species including all federally-listed species	This most likely will be an on-going process- but needs a big jump start
4	Control of non-migratory waterfowl	Water chemistry and a lack of a Texas wild-rice seed bank in the wild	**H**	**$**	All	None	Cleaner parks, an increase in the Texas wild-rice seed bank in the wild, and cleaner water	
4	Dredge fine sediment from specific areas of the river	Shallowing of the river	**M**	**$$**	All	Accidental removal of organisms during dredging	Less turbidity, more available habitat for native aquatic species	Designed to replace missing natural river processes due to flood control structures
4	Remove structures that create channelization of river and affect natural flow regimes	Channelization of the river and non-natural flow regimes	**MH**	**$$$**	All	Possible negative ecological impacts during construction	Natural bank species return and natural flow regimes return	
4	Emergency planning for drought, floods and spills	Loss of habitat for native aquatic species	**MH**	**$**	All	None	The saving of native species in times of drought, floods and catastrophic spills	

5	Build wetlands and wetponds	Sedimentation and pollution in the river	**M**	**$$$**	All	Land availability	Less sedimentation and better water quality	
5	Acquire land for retrofitting developed areas to follow better watershed protection	Sedimentation and pollution in the river	**M**	**$$$$**	All	Land availability	Less sedimentation and better water quality	
5	Acquire land for conservation purposes	Sedimentation and pollution in the river	**M**	**$$$$**	All	Land availability	Less sedimentation and better water quality	
5	Create a zoning and management plan for the San Marcos River watershed	Sedimentation and pollution in the river	**MH**	**$$**	All	None	Less sedimentation and better water quality	
5	Create watershed stewardship programs	Sedimentation and pollution in the river	**M**	**$**	All	None	Less sedimentation and better water quality	
5	Create more stringent Structural and Non-structural BMPs	Sedimentation and pollution in the river	**H**	**$**	All	None	Less sedimentation and better water quality	
5	Better/More enforcement of BMPs	Sedimentation and pollution in the river	**H**	**$**	All	None	Less sedimentation and better water quality	
5	Rebuild streets near river for better water quality control	Toxic materials associated with coal tar in the river ecosystem	**M**	**$$$$**	All	None	Reduction of toxic hydrocarbon derivatives	
5	Create low-cost loan programs for rain collection	Water quantity	**L**	**$$$**	All	None	More water in the river	

1. **Develop educational publications:** A comprehensive education plan will be developed to educate river users and other stakeholders on the importance of the San Marcos River ecosystem and teach them how to protect it. Educational tools to be developed will include but not be limited to an educational website targeting teachers, publications such as brochures and factsheets, traveling exhibits, demonstration sites, media releases, and community talks. Topics addressed will include the impact of invasive species, conservation of rare and endangered species, effects of aquarium dumping, trash input into the river, and maintenance of riparian habitats.
2. **Develop an internet presence to market existing and upcoming education materials:** self-explanatory.
3. **Develop travelling exhibits and demonstration sites:** See description of Develop education publications.
4. **Increase enforcement of park/city rules re: polluting and aquarium dumping:** Self explanatory
5. **Remove floating debris from Texas wild-rice stands:** Periodically, floating mats of dead and non-rooted vegetation along with garbage get trapped on top of Texas wild-rice stands. These mats inhibit light from getting to the plants for photosynthesis. The mats need to be removed from the stands on a consistent basis. The mats need to be taken out of the river and not pushed downstream. The floating plant debris can be composted. Vegetation clippings floating downstream, originating from the maintenance of Spring Lake via Texas State University's cutter boat, needs to be eliminated.
6. **Relocate Texas State University watercraft classes to Spring Lake:** Currently, Texas State University watercraft classes are given in areas near Texas wild-rice, and new boaters tend to trample of the endangered plant when falling out of their watercraft. The classes need to be moved to an area without Texas wild-rice nearby such as Spring Lake.
7. **Create pre-determined access points into the river:** Permanent access points will be combined with bank stabilization for the locations designated which avoids Texas wild-rice areas. They will serve as entry and exit ways that could be used by canoeists, tubers, swimmers, etc., while stabilizing highly eroded banks. In these areas, the bank is eroding due to natural river dynamics in combination with intense recreational use. The City plans to stabilize banks in at least six areas (City Park, Hopkins Street Underpass, Bicentennial Park, Rio Vista Park, Ramon Lucio Park and Cheatham Street underpass). The City Park project will be 370 m^2, and the remaining projects will measure about 100 m^2. Terrestrial and aquatic vegetation in the vicinity of these sites will be monitored pre- and post-construction to determine the effects.
8. **Create non-access points in sensitive areas:** Banks will be stabilized using prohibitive (thorny, sharp, etc.) plants, so that recreationists will be deterred from entering the river in those areas. Terrestrial and aquatic vegetation in the vicinity of these sites will be monitored pre- and post-construction to determine the effects.
9. **In-stream barriers as needed to protect habitat:** During low flow periods or during occasions of high recreational traffic (e.g., Texas Water Safari), place

buoys or another form of barrier in the water, protecting sections of the river that provide habitat for federally-listed and state-listed aquatic species.

10. **Involve riverside landowners in riparian management:** Educate riverside landowners on the importance of riparian buffer zones and possibly create other incentives that will increase the implementation of better riparian management practices.
11. **Remove elephant ear from the river:** The aquatic plant known as elephant ear (*Colocasia esculenta*) is considered an invasive species that directly competes with a number of native species along the banks of the San Marcos River, including Texas wild-rice. Elephant ear will be systematically removed in order to increase available habitat for native plant and fish species. Removal of this species should occur methodically and in tandem with the planting of native species so as not to encourage destabilization of the river's bed and banks.
12. **Remove invasive trees from the river's riparian zone:** Invasive plant species have increased in number and distribution within the river's riparian zone, competing directly with beneficial native species and altering wildlife habitat. Removal of invasive species should occur methodically and in tandem with the planting of native species so as not to encourage erosion or bank destabilization. Control of invasive species will require continuous monitoring in order to prevent re-establishment.
13. **Reintroduce native riparian vegetation:** Vegetated riparian zones provide a number of critical functions within a watershed. Acting as an interface between uplands and the river, these zones stabilize river banks, prevent erosion, protect water quality by filtering runoff and pollution, provide habitat for terrestrial wildlife, and provide canopy cover critical to fish habitat. The reintroduction of native riparian vegetation should occur in tandem with the previous action item, as well as independently throughout the river corridor where the riparian zone is absent or impaired.
14. **Prune riparian vegetation:** In some areas of the river, specifically near the I-35 bridge, riparian vegetation forces watercraft users to canoe/kayak over Texas wild-rice stands due to low-hanging branches. At low flows, the movement of the paddles can do damage to the plants. During low flows, a plan needs to be in place in order to create alternate pathways for watercraft so as not to disturb the Texas wild-rice. One easy way to do this is to prune the riparian vegetation that would normally block pathways over deeper water.
15. **Relocate coarse woody debris (CWD) from areas immediately upstream of Texas wild-rice:** When CWD is located within a meter upstream of Texas wild-rice or is on top of a Texas wild-rice stand, a plan needs to be put in place to relocate the debris downstream of the stand(s).
16. **Create a riparian buffer zone along the river's edge and tributaries:** Riparian buffer zones are important natural biofilters, protecting aquatic environments from excessive sedimentation, polluted surface runoff and erosion. These zones need to be present along the entire river's edge, including tributaries.
17. **Create Fish Passage Structures in Spring Lake Dam and Rio Vista Dam:** Install structures such as a fish ladder or bridge within the dams that are already in place to allow for fish migration upstream.

18. **Create an emergency plan for the possible case of dam failure:** Put together a plan that describes what actions need to take place and in what order, in case of dam failure in order to protect aquatic vegetation from becoming dewatered.
19. **Cummings Dam and Capes Dam alteration:** Alter these two dams in such a way that will allow for more potential fountain darter and Texas wild-rice habitat, both upstream and downstream of the dams (e.g., removal or lowering of the dams).
20. **Create/Fulfill a landscaping plan if dam alteration will be put forward:** This ties together with the previous action item. If dam alteration is a viable option to increase potential Texas wild-rice and fountain darter habitat, in order to stabilize banks as well as make the alteration a smooth process for the landowners that would be affected by the alteration, a landscaping plan must be put into place. The landowners will require access to the river for both their livestock as well as their own recreation.
21. **Annual monitoring of in-stream biota:** Surveys of all native and invasive plants and animals need to performed on an annual basis in order to learn how the ecosystem is changing and what species are being introduced into the river.
22. **Remove invasive plant species that negatively affect native species:** Invasive plants, particularly hydrilla and hygrophila, will be removed in phases beginning in Spring Lake and working downstream to the Blanco confluence. The removal method has not yet been determined. The area of removal will be replanted with native aquatic plants and weeded until the reintroduced plants can outcompete the invasives. Removed plants will be composted in an area outside of the floodplain.
23. **Reintroduce native aquatic plants:** Native plants, such as *Zizania texana, Sagittaria* sp., *Ludwigia repens*, *Potamogeton illinoisensis*, *Heteranthera dubia*, and *Cabomba caroliniana*, will be planted in the main corridor. Edges will be planted with *Zizaniopsis* sp. as well as other edge species. Exotics will be continually removed from the sites until the native plantings are established. The replacement plants will come from the Aquatic Nursery at Aquarena Center in San Marcos, TX and the San Marcos National Fish Hatchery and Technology Center to ensure no introductions of associated biota. These greenhouses propagate aquatic plants taken only from the San Marcos River.
24. **Remove invasive animal species that negatively affect native species:** Invasive animals will be removed (either on a continuous basis or as opportunities arise) by physical or other means as necessary to control the species.
25. **Control non-migratory waterfowl:** self-explanatory
26. **Dredge fine sediment from specific areas of the river:** Fine sediment will be removed from the river bottom at various locations within the San Marcos River. Sediment has accumulated due to the urbanization of the watershed and the installation of five flood control dams. As a result, the river is losing depth and width. Hydrosuction is a possible method to remove accumulations of sediment, but care would need to be taken to not remove biota. Although landscape controls need to be established on the various sources of sediment in the watershed, this project would remain long-term. Modeling could be done to decide how often the dredging should occur in order to make up for the loss of natural processes due to flood control structures.

27. **Remove structures that create channelization of river and affect natural flow regimes:** Natural banks and shorelines are significant features of a stable functioning riverine ecosystem, providing access and habitat for fish, wildlife, and plant species. Additionally, natural banks are more adept in absorbing hydraulic energy during flood events and allow the channel to adjust itself appropriately to changes in flow regime. Structures creating channelization and/or affecting the natural flow regime will be removed in order to enhance stream stability and increase available habitat.
28. **Emergency planning for drought, floods and spills:** Put together a plan that describes what actions need to take place and in what order, if the San Marcos River experiences drought, floods and catastrophic spills in order to protect the river ecosystem and its federally-listed and state-listed species, including limiting recreational access.
29. **Build wetlands and wetponds:** Wetlands and wetponds will be created within the San Marcos River watershed in order to decrease the amount of pollutants and sediment entering the river.
30. **Acquire land for retrofitting developed areas to follow better watershed protection:** The San Marcos area has undergone rapid development for over two decades without consideration for preserving the water quality of the San Marcos River. The areas that have already been developed can be retrofitted with various BMPs that work to reduce the pollutant concentration in stormwater runoff. A master plan would be developed to meet this goal with the pollutant loading standards based (at a minimum) on TCEQs water quality standards.
31. **Acquire land for conservation purposes:** For areas not yet developed or sparsely developed, land needs to be acquired through fee simple acquisition, conservation easement, purchase of development rights, or other means. A master plan needs to be developed (as part of the urban area masterplan above) to designate areas that have the highest potential for water quality improvement. Some of these properties need to be considered for regional wetland development.
32. **Create a zoning and management plan for the San Marcos River watershed:** Zoning determines land use and is therefore a critical tool in watershed management. An overall watershed management plan needs to be developed that will incorporate zoning and all other actions taken to improve water quality for the San Marcos River, including those previously mentioned in this matrix. A watershed plan addresses the entire area that affects a water body and thus is the beginning point for planning for water quality enhancement. A small group of stakeholders in San Marcos has begun working toward this goal, beginning with the Sessom Creek watershed. Grants are being researched to help fund the development of an overall plan.
33. **Create watershed stewardship programs:** Interested citizens from throughout the watershed will learn how to protect the San Marcos River. A Watershed Stewardship Manual would be developed to accompany these classes and would include materials on each of the class topics. Classes would consist of presentations, activities, and hands-on training led by experts in each field. Topics could include:

- Introduction to Watershed Hydrology
- Wetland Plant Identification (FIELD)
- Water Quality Monitoring
- Water Quality Monitoring (FIELD)
- Drinking Water (with tour of water supply facility)
- Waste Water (with tour of wastewater facility)
- Conservation Development
- Policy & Community Involvement

Several types of volunteer programs could be developed, such as watershed monitoring, school outreach programs, community ecology programs, community partners for a healthy stream; associated activities would be storm drain marking, waterway cleanups, creation of neighborhood rain gardens, pet waste education, etc.

Stewardship groups could advance into taking the lead in developing restoration strategies and implementing solutions. It would be important to involve a variety of stakeholders including developers and conservationists; as well as state and federal agencies for technical assistance with projects. Additionally, financial resources from state and federal agencies with private funds, foundations, local businesses and corporations could be leveraged more easily with such a group.

34. **Create more stringent Structural and Non-structural BMPs:** Best Management Practices are required by the City for developments, but are primarily limited to silt fences and detention ponds. There is a diversity of practices in the market of BMPs that are more effective than silt fences or in combination with silt fences. Additionally, detention ponds do not address water quality, only quantity. The Center for Watershed Protection has a plethora of detailed guidance for municipalities addressing this issue. The City has begun looking at these ideas and should adopt more stringent practices. Also, in the near future, TCEQ will require the City to comply with its water quality practices requirements for cities with a population of 50,000 or greater.
35. **Better/More enforcement of BMPs:** A regulation is only as good as its enforcement.
36. **Rebuild streets near river for better water quality control:** No coal tar derivatives in street materials within the San Marcos River watershed.
37. **Create low-cost loan programs for rain collection:** Offering low-cost loans to homeowners to install rainwater collection systems (potable and/or non-potable) would allow for the installation of rainwater collection systems on all new construction, retrofitting existing structures to capture rainwater where possible, the development of stormwater capture reservoirs (a form of rainwater collection), and would in turn reduce demand on the Edwards Aquifer, and reduce stormwater runoff.

Appendix I

Goal #	**Research Needs** *** = currently being conducted**	**Priority Ranking**	**Estimated Cost**
2	Where are people entering the river and what size area is affected per access point?	**H**	**$**
2	What is the best width and slope of proposed access areas?	**M**	**$**
2	What is the projected growth for the region?	**M**	**$**
2	Where do river-users park and what route do they take into the river?	**L**	**$**
2	What size buffer is needed around Texas wild-rice stands?	**H**	**$$**
2	What is the minimum riparian buffer zone needed for benefit to the river?	**H**	**$$$**
2	What is the current riparian vegetation? *	**M**	**$$**
3	What would altering Capes and Cummings Dam do to Texas wild-rice and fountain darter potential habitat? *	**H**	**$$**
4	What are *Protoptila arca* (San Marcos Saddle-case Caddisfly) habitat requirements and population estimates?	**M**	**$$**
4	How has the San Marcos River changed in bathymetry over a 10 year period? *	**H**	**$$$**
4	How has the macrophyte community of the San Marcos River changed in over a 10 year period? *	**M**	**$$**
4	How do CO2 levels and temperature change with changing spring flows? *	**M**	**$$**
4	What are the affects of CWD on the river bottom during flood events?	**M**	**$$**
4	Is water clarity or CO2 the reason behind low numbers of Texas wild-rice in the lower part of the upper San Marcos River?	**H**	**$$**
4	What are San Marcos River native mussel habitat requirements and population estimates?	**MH**	**$$**
5	How would the river and its banks change if large sediment islands that have formed due to poor stormwater management were removed? (Just upstream and just down stream of the University Dr. Bridge)	**H**	**$$**
5	What is the percent impervious cover in the San Marcos River watershed?	**M**	**$**
5	What are the maintenance requirements for detention/retention ponds? How long before they no longer function?	**M**	**$**
5	What areas do not have but need detention ponds?	**M**	**$**