Sustaining our water resources

Watersheds are nested drainages, incorporating the entire land surface that collects water flowing to a geographic point. Different maps and planning documents refer to the Laguna channel and the Laguna watershed in different ways, sometimes splitting off the Santa Rosa and Mark West Creeks as separate drainages. Within this plan, we define the Laguna watershed as the area that incorporates all these sub-basins, and when this definition needs to be underscored the phrase “greater Laguna watershed” is applied. This watershed definition is more ecologically appropriate, reflecting the biological and physical properties of the system. However, for regulatory purposes, the Laguna, Santa Rosa Creek and Mark West Creeks are split into separate drainages, as discussed below. Water quality concerns in the Laguna cannot be easily separated from the issues related to the Laguna’s hydrology and water dynamics. Restoring the Laguna’s water resources will require integrated research, planning and collaboration.

Hydrology

High gradient creeks, vernal pools, slow moving channel

The Laguna watershed has a complex and diverse hydrology—cool-water high-gradient creeks in the upper watershed flow down the hillsides to the broad, flat, vernal pool-dotted Santa Rosa Plain, meeting the warm, slow-moving Laguna main channel, that flows northward to join the Russian River. During very large storms, the Russian River backs up into the Laguna’s low-gradient basin near Windsor and Mark West Creeks: this alleviates flooding in the lower Russian River valley, and strongly affects the Laguna ecosystem. In part because of these back flows, and in part because of localized topographic constrictions, the Laguna does not have scouring floods, and retains much sediment within its channels and floodplains. During late summer, the Laguna becomes a series of disconnected ponds—with little or no surface flow—while shallower reaches become dry or marshy, and deeper areas become temperature stratified. The upper reaches of the Laguna’s main tributaries stay relatively cool in streambeds with overhanging riparian vegetation.

Backflow, sediment retention, disconnected ponds

Cool upper reaches

The Laguna's hydrologic complexity contributes to its biological diversity but creates challenges for watershed planning. How do we retain the natural values and ecosystem function of the system while protecting the communities of the Santa Rosa Plain and lower Russian River from flooding?

Changes over time

Historically, streams flowing down from Sonoma, Taylor and the Mayacama Mountains formed broad alluvial fans as they deposited sediments over the east side of the Santa Rosa Plain. Small channels crisscrossed this fan, naturally overflowing and changing course each year. Many of these streams disappeared underground or diffused into open swampland. Where the alluvium ended, the clayey soils on the western side of the plain formed numerous small swales and pools, connected during heavy rainwater events, but disconnected during the late spring season, and drying up completely in the summer months. In the summertime, the Laguna's bottomlands were comprised of a chain of wetlands, lakes and braided waterways. As water levels rose with the return of the winter rains, the Laguna's ponded lower areas overflowed forming a broad connected floodplain swelling and shrinking with each winter storm.

Alluvial fan

Wetlands, lakes, braided channels

With the post-Gold Rush advent of American settlement, farmers sought to gain use of bottom land and swamps by constructing ditches to improve local drainage. Later, flood-control districts were formed to contain the creeks in predictable channels, and to protect new neighborhoods and roads. Marshes were drained into ditches, and streams were straightened to rapidly move water away from urban areas. A number of flood control structures were built, including the Matanzas Reservoir and modifications to Spring Lake. By the late 1960s, virtually all the stream channels on the Santa Rosa Plain had been altered. For many years, keeping these channels clear was a scheduled maintenance activity of SCWA (then called the Sonoma County Flood Control and Water Conservation District); cutting away vegetation, and removing silt and debris jams. In the 1970s, heightened environmental awareness changed public attitudes about these activities, and channel maintenance became tightly regulated. These attitudes are now coming full circle, as SCWA has recently come under public criticism for failing to maintain the channel's flood capacity.

Ditches and channels

Flood control district

The Laguna hydrology continues to change, as development increases paving, rooftops and other impermeable surfaces. Under these conditions, rain and floodwater have less opportunity to soak into the soil and water

Development and impermeable surfaces

flows more rapidly along the ground, eroding ditches and roadsides, and picking up sediment and debris. More water enters the stream system, and that water carries more sediment and debris. In a corollary to this, increased runoff reduces groundwater recharge. Many residents living in unincorporated areas are dependent on well water, and are concerned about the sustainability of groundwater supplies—especially since reduced recharge has been accompanied by greater demands from exurban development and agriculture. Likewise, hopes for restoring salmon and steelhead populations in the Laguna tributaries depend on maintaining summertime stream flows, which are affected by the movement and availability of water from surface, sub-surface, and groundwater sources.

Groundwater

Flooding, erosion and sedimentation are natural, desirable processes in a well-functioning stream ecosystem and are thought to be essential for maintaining biological diversity. Floodwaters maintain healthy riparian communities; and sediments build fertile soils on floodplain farmlands. Within any reach, there are always areas of active erosion and active deposition, but a stream is considered to be stable when these rates are roughly in equilibrium along its length. If conditions shift to favor either erosion or sedimentation, stream character can change dramatically, with serious repercussions for nearby roads and houses. In the Laguna watershed, accelerated upstream erosion has not been accompanied by accelerated downstream sediment transport. In some areas, sediment has been trapped behind dams or other flood control structures, increasing erosion immediately downstream. Overall, however, much of the sediment now settles out in flood control channels on the Santa Rosa Plain. Thick deposits of fine sediments encourage aquatic weed growth in the active channel, and this vegetation traps further sediment. These are all natural physical processes, as the system attempts to reestablish equilibrium, but the rate of these physical processes has been greatly accelerated, with serious consequences for developed areas and the ecosystem as a whole.

Natural, desirable processes

Accelerated erosion and sedimentation

The diversity of Laguna wetlands is a central reason for the Laguna's biological diversity. Vernal pools and swales, sedge-dominated high marshes, tule-dominated low marshes, seasonal flood plains and perennial creeks and streams all support different plant and wildlife communities. Maintaining habitat diversity is one of this plan's most important goals. Hydrological studies and restoration plans should balance the needs of all these habitat types and not favor only perennial streams.

Balancing needs for diverse habitats

The 2004 Laguna Sedimentation Study, commissioned by the US Army Corps and the SCWA (PWA 2004) roughly estimated that an average of 1½ feet of sediment has been deposited in the lower Laguna-Mark

West reaches between 1946 and 2002. Accounting for projected build-out, they predicted that sedimentation rates will accelerate, increasing flood elevations by 2½–3 feet over the next 50 years. These predictions are based on models that view the Laguna system as a giant bathtub, slowly losing capacity as it fills with sediment. In practice, sediment does not settle out uniformly but collects in particular areas, based on local geography and vegetation or other factors. For example, channel cross-section surveys found that between 1957 and 2002, three feet of sediment had accumulated in the Laguna channel immediately south of Santa Rosa creek. Neighboring residents have recently observed a dramatic increase in water levels, consequently killing large areas of riparian forest that have now been replaced by fields of *Ludwigia*. At another site downstream, soil cores show only 2 inches of sediment accumulation over 50 years. Based on these patterns, it is clear that some areas of the Laguna will receive much greater than 3 feet increases in flood elevation over the next 50 years, and some areas may receive much less. The PWA Study found that coarse, medium and fine sediment enters the system from a variety of sources in the upper watershed: from gullies, channel erosion and debris flows, to road runoff associated with urban/suburban development. Different control strategies will be necessary for each type and source of sediment, but all point to a need for vigilance, the use of best management practices, and environmental restoration.

Sedimentation Study predictions

Despite intense, long-standing community interest in issues related to Laguna hydrology and hydraulics—flood control, water supply and water quality, as well as habitat restoration and soil conservation—there is surprisingly little empirical data on how the watershed's hydrology functions as a whole. Also lacking are models of how water issues are interrelated. One of the foremost recommendations of this plan is to expedite an integrated hydrology research program for the Laguna watershed. We have entered an era of anticipated global environmental change. Climate change scientists forecast an increase in climatic extremes, of both severe droughts and intense storms. Compounding this, local changes in the patterns of development will increase the rate and quantity of surface water flows and erosion. The combination of these factors means that indices like the 100-year floodplain elevation will change position on the elevational gradient; that is, the elevation for which there is a 1/100 chance of flooding is going to shift. Having an established network of monitoring stations, along with detailed analyses of the floodplain contours and good hydrologic modeling tools will be essential to guide urban and environmental planners, as well as to guide agencies responsible for providing flood protection and

Empirical data on watershed's hydrology

pollution control. Such a research effort is consistent with recommendations in the county's Draft General Plan 2020 (D-GP2020)

Research and monitoring needs

Coordinated, watershed-scale studies and modeling are a critical first step for developing a baseline characterization of the watershed and predicting future changes in year-round water dynamics. There are a number of different agencies conducting research on the dynamics of water flow and sediment transport in the Laguna, but these efforts are not fully integrated with one another.

The SCWA and US Army Corps of Engineers are evaluating flooding patterns in different parts of the watershed. Together they co-sponsored the Sedimentation Study described above, and currently they are working with the US Geological Survey to model sediment transport through portions of the Laguna main channel. The December 31, 2005 flooding within the cities of Rohnert Park and Cotati tested the area's flood control channels. Modifying these channels to increase capacity and flow could prevent a recurrence of such floods, but doing this may increase risk of flooding at the Laguna Treatment Plant, which would have drastic impacts to downstream water quality; moving water more rapidly past the Laguna Treatment Plant potentially increases flood risks to the City of Sebastopol; and moving water rapidly past Sebastopol increases flood risks to property owners downstream all the way to the Russian River. Watershed models are essential for evaluating flood protection options, including the feasibility of constructing sediment catchment basin or reservoirs on the east side of the Santa Rosa Plain, or increasing holding capacity in open areas of the flood plain.

SCWA

Army Corps

US Geological Survey

For many reasons, restoration planning depends on understanding Laguna watershed hydrology. Accelerated changes in flood levels and water retention on the floodplain will affect the long-term viability of restoration projects; for example, if areas with restored riparian forest convert to high marsh, restoration plantings will not survive. Likewise, if low-flow channels are installed without understanding sedimentation patterns, we may not be prepared for the rate of in-fill. The USDA-ARS is collaborating with NASA to develop a project to assess the effects of Laguna hydraulics and hydrology on invasive plants. NOAA Fisheries and CDFG are concerned with fish passage, channel conditions and water supply, especially in the upper watershed: restoring fish populations requires an understanding of the links between groundwater and surface water hydrology. The North Coast Regional Water Quality Control Board

USDA-ARS

NOAA

CDFG

NCRWQCB

(NCRWQCB) also needs hydrologic data to support TMDL pollution control planning for water quality impairments in the watershed. Ideally, a concerted study of hydrology would lead to the development of a full water budget for the Laguna and its tributaries.

Each of these studies is necessary for understanding the current dynamics of the basin and for predicting how future plans would shift these dynamics. Ideally, we need a basin model that incorporate hydrologic, topographic, land use and ecosystem information. A basin model such as this could feed into and integrate with more detailed models at the scale of individual reaches. Together, these will be essential for forecasting the effects of major storms on the hydraulics of the floodplain, for predicting natural changes to channels, for identifying ways to improve water quality, and informing plans to restore riparian habitats and channel contours. However, watershed models are only as valuable as the data that goes into them, and require an expanded network of monitoring stations.

Basin model

Stream surveys and flow monitoring

At this time, the Laguna has a relatively limited network of gauging stations. These need to be expanded to better characterize flow regimes, to better understand how flows link to environmental processes, and to assist in flood protection assessment. There are also few cross-sectional surveys of the floodplain and channel. And furthermore we have very limited knowledge of stream conditions where waterways pass through private property: these include portions of most tributaries, as well as much of the Laguna main channel between Guerneville Road and the Russian River.

Cross-sectional surveys

Meteorology

Another gap is the lack of weather data coverage for different parts of the Laguna watershed. There are substantial microhabitat differences in rainfall and temperature, between Sebastopol and Santa Rosa, and from the bottom of the Plain to the upper hillsides. Although there are few official weather stations, many local weather buffs maintain their own stations, recording wind speed, temperature and rainfall. The efforts of these meteorology monitors should be organized and coordinated, and the data gathered into the Laguna Ecosystem Database.

Weather stations

Topography

The Santa Rosa Plain has little topographic relief, so that during large storms mere inches of elevation change can determine whether an area is subject to flooding, and how long water is retained into the summer. *Ludwigia*, and other plants are sensitive to differences in water levels and the dynamics of water retention throughout the year. For these reasons, predicting flood events, developing water management-based control methods for *Ludwigia*, and riparian restoration planning, all require high-resolution topographic mapping, such as surface-based LIDAR. With such a sub-meter digital elevation model (DEM) it will be possible to identify areas that can accommodate more floodwaters, by breaching levees or making other modifications.

LIDAR-based DEM

Soils and land use

Soils and land use have substantial effects on the hydrology and hydraulics of the Laguna. Soil stability determines the extent of erosion and gully formation. Land use affects runoff, sedimentation and water quality. GIS analyses allow land use to be categorized in hydrology models: this helps to quantify contributions from these sources, and improve the model's usefulness in predictive scenarios. The Laguna Sedimentation Study used aerial photos and ground reconnaissance to identify areas where severe erosion was occurring from hillsides, banks and channels. Non-point sources from agriculture, roadsides and urban areas may also be contributing substantial amounts of sediment, although they are individually dispersed and are each small in scale. A number of agencies and organizations have surveyed different drainages for sites of active erosion, and implemented erosion-control projects; however, many more on-the-ground surveys are needed to describe current conditions.

Land use categorization

On-the-ground surveys

Infiltration

Capturing surface water in a distributed network of infiltration basins is a promising method for reducing storm water volume and associated water quality problems, and is now required for many new and re-developments under the newly-adopted Standard Urban Stormwater Mitigation Plan (SUSMP). Brock Dolman, from the Occidental Arts and Ecology Center, refers to this as the "slow it, spread it, and sink it" method. Many of these techniques incorporate vegetation to slow lateral flows and accelerate infiltration, which can also provide habitat benefits. Ideally, the possibility of incorporating infiltration mechanisms into existing developments should be explored. Improperly constructed storm water basins can become sources of mosquito production, and engineering effort is needed to ensure that designs are well sealed and drain properly.

"Slow it, spread it, sink it"

Restoration, management and policy recommendations

Because of the current and projected development on the Santa Rosa Plain, we cannot fully restore the natural functioning of vernal pools, swales, subsurface flows, and late spring evaporation. Instead, we should find ways to re-engineer constructed channels, ways to better protect the few remaining natural creeks, ways to maintain the diversity of wetland habitats, ways to restore necessary functional processes, and ways to allow flooding to occur in areas that accommodate it. This will depend on the studies described above. Small scale prescriptions for restoring the Laguna's ecosystem and hydrological stability are outside the scope of this plan.

Finding ways to restore hydrologic function

In general, stream systems are stabilized by restoring appropriate widths and depths to bank-full channels; restoring channel length by matching the low gradient of the Santa Rosa Plain to a greater channel sinuosity; and by enhancing vegetation along channel boundaries. These solutions depend on the location of existing infrastructure and channel setbacks, many of which are very narrow in urbanized areas. The current zoning code for the City of Santa Rosa calls for 50-foot setbacks for new construction, but in many existing developments, the *de facto* setback is only thirty feet. Narrow setbacks reduce the ability to restore meanders to allow natural stream processes, and to have adequate vegetation for protecting banks. Some areas may be permanently subject to erosion and sedimentation, and without addressing the underlying problems, threats to neighborhoods will increase as the channels attempt to re-equilibrate. The D-GP2020 recommends 100-foot riparian setbacks on streams throughout the Laguna watershed, measured from the top of the higher bank on either side of the stream, which is a good place to start. Depending on topography, and the area of drainage served, setbacks in some areas may need to be wider or narrower.

Riparian setbacks

Over the long term, flooding can be alleviated through a combined set of practices, including: 1) stabilizing the stream system as described above, reducing erosion, and restoring riparian corridors along stream channels; and 2) increasing infiltration throughout the system, recharging aquifers, and reducing runoff: this can be accomplished by a distributed network of infiltration and retention basins, increased use of technologies such as permeable paving, and greater use of natural vegetative buffer strips. Almost all erosion issues can be alleviated to a great degree by environmental restoration, as discussed in chapter 4. Flood-risks can further be reduced by: 3) protecting the floodplain from fill and encroachment: restricting construction, and in some cases removing or redesigning infrastructure, such as bridges and ponds, situated in flood-prone areas; 4) vegetation management, striking a balance between the need for vegetated riparian corridors, and the need for waters to move freely through them; and 5) sediment removal in key areas, especially where there is naturally high

Stabilization

Infiltration

Floodplain protection

Vegetation management

Sediment removal

sediment accretion. While we would like to view sediment removal as a short-term solution while sediment control measures are put in place in areas of active deposition—in particular, portions of Rohnert Park—it may be necessary to incorporate ongoing sediment removal in restoration plans simply because we have yet to learn how to develop naturally sustainable methods of flood hazard protection on alluvial fans. The D-GP2020 has similar policy recommendations for limiting flood damage and related hazards, including: a shift of emphasis from flood control structures to flood plain management, and promotion of interagency coordination for surface water management.

Many of these solutions involve complex or otherwise sensitive land-use decisions, and will need the best possible information in order to make wise planning decisions. Currently, the 76-foot iso-elevation line is used to define the 100-year floodplain for much of the Laguna watershed, and the FEMA flood insurance rate map is closely correlated to this. However, the D-GP2020 does not limit floodplain development in unincorporated areas, although it calls for structures to be raised at least one foot above this elevation, and for a policy of "no net fill"—with equivalent material being removed to compensate for lost flood storage capacity. The danger with construction in low-lying areas is that the location of the 100-year floodplain is not static. Increased sedimentation, changes in rainfall patterns and intensity associated with global climate change, and a net increase in impervious surface area will continue to alter the pattern and severity of flooding. Wherever feasible, construction should be restricted from areas near the floodplain and any essential infrastructure should be built to withstand periodic inundation. FEMA grants and loans often do not compensate for the full costs of flood damage, which are then borne by individual homeowners and public agencies. At a minimum, FEMA-designated flood zone maps need to be regularly updated and consistently consulted by planners.

FEMA flood insurance rate map

Restoring channel meanders and protecting the floodplain may require land acquisition or conservation easements. These should be given priority by the Sonoma County Agricultural Preservation and Open Space District, the Sonoma Land Trust, or other agencies and organizations with the capacity for acquiring land and easements. Such acquisitions support the public trust by reducing the risk of flood damage, protecting environmental values, improving water quality and keeping open space available for agriculture.

Acquisitions and easements: SCAPOSD, Sonoma Land Trust

Although there are great benefits to restoring riparian trees and shrubs, vegetation management is also important for maintaining the flood hazard reduction capabilities of this somewhat-artificial system. Water needs to be conveyed from upstream reaches to downstream reaches in ways that do not create safety hazards at bridge crossings and on nearby roads, or to man-made structures that are subject to flooding. Trees and other woody plants can contribute to flooding when they grow into streams that pass through urban and residential districts. Multi-trunked willows, *Arundo donax* (giant reed) and Himalayan blackberry are particularly problematic—filling channels, trapping debris and forming dams. Although "large woody debris" is beneficial for steelhead and salmon, especially in the upper watershed, debris piles are less appropriate for developed areas on the Santa Rosa Plain. Cattails, tules, and other densely-growing aquatic plants may contribute to flood-control problems by accreting sediments. The key is to maintain healthy vegetation at the edges of channels, but to discourage woody plants within low-flow channel banks: one good strategy for stream channel maintenance is to remove problematic trees from the north side of stream banks and to compensate for their loss by accentuating tree densities on the southern bank. In the end, without good flood protection, it will be difficult to sustain public support for riparian restoration, especially in urban areas.

Debris

Vegetation at the edges

Water quality

The headwaters of many of the Laguna's tributary streams once supported substantial populations of steelhead trout, and ran clear and cold through densely-forested ravines. In contrast, the main channel was a eutrophic complex of wetlands and waterways that supported warm-water fish throughout the year, and provided a migration corridor for steelhead and coho moving between headwater streams and the ocean. These slow-moving, low-gradient waterways accumulate organic debris during winter floods, which release nutrients through decomposition, supporting tule and other emergent wetland plants. Vast marshes at the southern edge of the watershed would have helped filter sediment and nutrients before reaching the main channel, but the water in low-lying areas was always warmer, shallower and lower in dissolved oxygen than waters in the mountain streams. Many of these natural processes are still in place, but have been strongly affected by human development in the basin. For many years, cities discharged untreated effluent directly into the creeks; and although this is no longer the case, recent urban growth has vastly increased the amount of impermeable surface area, escalating run-off of polluted stormwater. The Laguna main channel is now subject to dense

Steelhead and coho corridor

aquatic weed infestations. However, the watershed is still characterized by diverse aquatic habitats—wetlands, streams and channels—with diverse plant and animal communities, and spatial and temporal variation in water quality.

Diverse aquatic habitats

The North Coast Basin Plan's regulatory definition of the Laguna de Santa Rosa sub-basin includes only the portions of the channel and associated tributaries south of Santa Rosa Creek. As described above, we've defined a more geophysically inclusive definition of the greater Laguna watershed, incorporating both Santa Rosa Creek and Mark West Creek into the Laguna sub-basin. For regulatory purposes, the Laguna de Santa Rosa's beneficial uses and impairments listed by the Basin Plan are given for the sub-basin alone, although the ecological influence of these factors is felt throughout the greater watershed and the lower Russian River.

"Laguna sub-basin" versus the greater Laguna watershed

In 2006, the Laguna was listed under section 303(d) of the national Clean Water Act (CWA) for excess nitrogen, phosphorus, and suspended sediment, elevated water temperature, and low dissolved oxygen (DO). As the largest tributary to the Russian River, the Laguna's water quality also affects residents, many from low-income communities, along the river's lower reaches. These impairments affect the health of humans and the environment, as well as the local economy, because murky, nutrient-rich water is less attractive for recreation and depresses the local fishing industry. Water quality in the basin is regulated by the NCRWQCB, which is responsible for enforcing both the CWA and the state Porter-Cologne Water Quality Control Act, and has a mandate to protect and restore the Laguna's beneficial uses, as described in its Basin Plan (table 11 on page 431).

303(d) listings

Porter-Cologne Act and Clean Water Act

The Laguna's water quality impairments are complex and interrelated. Historic clearing of riparian vegetation has increased bank erosion and reduced the shade cover over stream channels, leading to shallow, warm water in some streambeds. Sediment from bank erosion and run-off is both a source and a sink (or holding area) for phosphorus. Phosphorus binds to the fine particles and is stored in the sediment layers, later to be released as sediments are disturbed. In a similar way, sediment can also retain or transport pollutants like mercury and pesticide residues. The presence of abundant phosphorus and nitrogen combined with sunny streambed conditions, favors plant and algae growth. Although plants add oxygen to the water through photosynthesis, they extract it again during the night, contributing to early morning DO deficits. Rampant vegetation interferes with flood control and mosquito abatement; and vegetation management programs using herbicides, grazing, or mechani-

Nutrient binding and release

Dissolved oxygen daily cycle

cal removal operations can create temporary water quality impairments. Decomposing plants deplete dissolved oxygen and can also increase water temperatures. Anaerobic, high nutrient conditions may also stimulate the conversion of inorganic mercury to the bio-available "methyl-mercury" form. The combination of warm water, low oxygen and suspended sediment creates marginal habitat conditions for cold-water fish species, and other forms of aquatic life.

Recent improvements

Despite these challenges, by many reports, aspects of the Laguna's water quality have improved over the past few decades. There is much greater public awareness and regulatory support for reducing water pollution; wastewater from the cities in the Subregional System (Santa Rosa, Rohnert Park, Sebastopol and Cotati) is highly treated, with innovative disposal methods for much of the tertiary-treated effluent; and agricultural producers have adopted new management practices to limit the amount of nutrients and sediment running off their fields during the winter rains. Nonetheless, recent increases in population density have increased the volume of treated wastewater that must be disposed of, and a simultaneous increase in impervious surface area, from new development, has increased the rate and volume of polluted runoff. While they are not the subjects of an EPA listing, there are several other pollutants of concern for the Laguna watershed, these include: copper, which leaches from home plumbing by reacting with slightly acidic tap water; bacteria, from garbage or failed septic systems; the residues of pharmaceuticals and personal care products that are washed down drains; and the residues of backyard and agricultural fertilizers and pesticides that enter the stormwater system.

Other pollutants of concern

TMDLs

Although we have a general understanding of the Laguna's water quality concerns, we have yet to quantify either the sources or the effects of particular pollutants, or even to characterize the beneficial uses we wish to protect. Total Maximum Daily Load (TMDL) pollution control plans are designed to provide a quantitative assessment of specific water quality problems in a given water body, as required by the federal 303(d) listing. The name refers to the total load of pollutants that a water body can receive and still protect its beneficial uses. TMDL plans are developed by the NCRWQCB along with local stakeholders, who help develop pollution reduction strategies. However, TMDLs are more than just regulatory mechanisms, and represent an opportunity to gain a comprehensive understanding of the processes affecting water quality in the basin. Ideally,

TMDL stakeholders

TMDLs identify where pollution is originating, estimate natural conditions, and evaluate the watershed's capacity to assimilate pollutants; for example, the natural processes that keep water cool or remove nitrogen. Based on this information, the plan develops regulatory standards for acceptable levels of pollution, which then form a basis for enforcing water quality laws. As part of this process, TMDLs make recommendations for best management practices and policy changes that can help restore water quality. The NCRWQCB is planning to initiate a TMDL process to address listed impairments in the Laguna de Santa Rosa, beginning in 2006 or 2007.

Watershed's capacity to assimilate pollutants

The first step is to characterize baseline conditions of the watershed—including hydrology (flow volumes and rates), hydraulics (water flow dynamics), land-use patterns, and ecological conditions in the channels. This will involve the same detailed modeling and topographic mapping that is needed for environmental restoration and flood control planning, as described above. Studies are needed to evaluate the system's internal nutrient cycling such as nitrogen fixation and denitrification, to better understand the cause and effect of current conditions. Low dissolved oxygen levels result from decomposing organic material, but it is not clear whether the main source of organic matter is from algae, aquatic plants, terrestrial origins or sediments. This information is key for developing effective interventions. As regulations are developed through the TMDL process, they must be fine-tuned to reflect the variability in the system. Processes and conditions are likely to be very different among different reaches of the main Laguna channel and between the Laguna channel and its tributaries. Naturally warmer areas, such as emergent wetlands alongside the main channel, support different plant and animal communities than do cool-water streams in higher-elevation tributaries, and need habitat-specific biological indicators for water quality. Surveys are needed to evaluate the environmental condition of waterways and riparian areas; especially as the quality of the riparian vegetation has the potential to strongly influence in-stream conditions.

Baseline conditions

Nutrient cycling and dissolved oxygen studies

Habitat-specific indicators

A TMDL is only as good as the data that goes into it; and part of the baseline characterization effort must be to coordinate and standardize the water quality monitoring programs now being done by different agencies and citizen groups. Most of the pollution in the Laguna is considered "non-point source," in that it arises from many small, dispersed sources, and gathers together via surface run-off. As a consequence, non-point source pollution requires geographically distributed monitoring to identify the primary causes of impairments. Because each agency or orga-

Geographically distributed monitoring

nization develops their water quality monitoring programs with different objectives, they use different methodologies and often test for different impairments. Different groups may also use instruments that vary in levels of sensitivity. To get a clear picture of how water quality changes across the watershed, these monitoring programs should be more uniform.

Knowing the precise source of pollution has many benefits. Without good data on where pollution originates, dialogue often turns to unconstructive arguments about who is responsible for the overall condition of the system. If the source of a problem can be accurately identified, then money and other resources can be allocated toward solutions. For example, researchers at the UC Extension service found that water quality sampling within agricultural operations were able to identify specific areas that could be improved in specific ways to reduce the bacterial contamination of waterways. The producers were then able to work with RCDs to obtain grants to stop the pollution at its source. In general, pollution-generating industries and other dischargers need to work diligently to improve their operating practices, but they should also be sheltered from litigation while they are actively working to remedy their infractions. TMDLs are best developed as a group endeavor, based on mutual trust, bringing together diverse stakeholders to seek mutually beneficial outcomes.

Locating pollution sources

Group endeavor, based on mutual trust

Erosion and sedimentation

The development of a TMDL for sediment will complement flood-control efforts by the SCWA and the U.S. Army Corps of Engineers to reduce erosion in the watershed. For example, increasing the agricultural and development setbacks along creeks, and enhancing riparian vegetation, will help stabilize banks while filtering sediments carried by surface run-off. It will also trap nutrients and prevent the heating of streamflow by shading channels. Suspended sediment (measured as turbidity) harms fish by coating gill tissues, limiting their ability to extract oxygen from the water. This is a problem both in the rearing and spawning habitat of the upper tributaries, and in the migratory habitat of waterways in the lower watershed. When fine sediment settles out of the water in spawning streams, it can smother developing eggs and interfere with juveniles' ability to find food. The first task for remediation is to find areas of active erosion, and develop plans to treat them. In some cases, large gullies or slides may be contributing large quantities of coarse and fine sediments, but overall, fine sediment is considered a "non-point source" pollution problem, with many small contributors distributed over a large area. The Laguna Sedimentation Study found that the main sources of fine sediments are

Suspended sediment harms fish

Sources of fine sediments

from urban and suburban development; gully expansion and road runoff; roadside ditches; channel incision and erosion; and channel maintenance activities. The USGS suggests that it is also likely that slumping hillsides and earthquake-triggered landslides are releasing substantial amounts of sediment into the system.

When the sources of sediment are so diverse and widely distributed, their solutions must also be diverse and widely distributed. Large erosion sites producing large amounts of sediment should be given priority, but projects should also be developed that address, for example, numerous small erosion-control projects. The *Coho Recovery Plan* specifically recommends that county and municipal Public Works and Transportation departments inventory and fix roadside erosion. It may be desirable to remove unused roads on state and regional parks in montane areas, and field surveys should keep this possibility in mind when investigating fish passage and fish habitat. The county and municipal governments have sediment-reduction commitments through the Standard Urban Stormwater Management Plan (SUSMP). Natural geologic forces are also a contributing factor to sedimentation. The USGS mapping of earthquake fault lines and unstable slopes provides a strong set of data for investigating erosion potential. Best management practices for new home construction in these areas needs to be more carefully monitored than in the stable, flat, low-lying regions of the watershed. PRMD designations for Rural Residential should continue to stay away from fault lines and unstable slopes.

Coho Recovery Plan

PRMD designations

Erosion control is a complex issue: streams that are depleted in coarse sediments have what hydrologists call "hungry water," that eats away channel banks. For this reason, simply trapping sediment behind dams can create its own set of problems, by increasing erosion and channel down-cutting further downstream. These dams may also impede fish passage. Eroded vertical banks are difficult to re-vegetate, and narrow riparian setbacks encourage engineered channelization, which, unless carefully planned, can further disrupt natural physical and biological processes. The best erosion-control measures are those that use re-vegetation techniques. Vegetation is self-sustaining and has the added benefits of trapping nutrients from surface runoff, shading the channel and improving stream habitat quality. Off-channel, vegetated swales and buffers can very effectively trap fine sediment and other pollutants in stormwater or agricultural runoff before they reach the waterways. The CDFG has developed an extensive *California Salmonid Stream Habitat Restoration Manual*, with best management practices and techniques.

Vegetation is self-sustaining

California Salmonid Stream Habitat Restoration Manual

Urban stormwater

During wet winters, large quantities of rainwater can wash pollution and debris off streets and yards and into stream channels. Pesticides, pet-wastes, oil and grease, fall-out from air pollution, and all manner of trash (tennis balls, plastic water bottles and other floating objects) travel essentially unfiltered into the Laguna. In the dry season, over-irrigation of lawns and recreational play-fields can carry off fertilizers and pesticides, un-diluted by rainwater, and in high concentrations. The sheer volume of storm water, and the lack of in-stream mechanisms for improving water quality make the problem logistically very difficult. In the Laguna watershed, storm water discharges are regulated by the NCRWQCB, which has issued a joint NPDES permit to the City of Santa Rosa, the County of Sonoma, and the Sonoma County Water Agency. These governmental bodies have developed a Storm Water Management Program (SWMP) to meet their permit obligations.

Storm Water Management Program

Part of the SWMP has been to institute a Standard Urban Stormwater Mitigation Plan (SUSMP), to moderate the effects of runoff from urban development and redevelopment; and to the "extent practicable," reduce storm runoff from existing developments. The overall goals of the plan are to prevent pollutants from reaching storm drains, to reduce the overall quantity of runoff, and to preserve natural areas as a way of filtering pollutants from surface flows. There are several reasons for targeting new and re-development, for example: 1) existing non-point pollution sources are very hard to remediate, beyond public education efforts; 2) developments tend to decrease overall vegetative cover that would normally filter pollutants, while simultaneously increasing impermeable surface areas—which act to accelerate flow rates—and allowing pollution to be carried along; and 3) developments increase human population density, bringing greater numbers of cars, lawn care chemicals, pet wastes, and trash that contribute pollution to the storm drain system. The newest generation of storm water management techniques emphasize engineered biological systems of swales, ponds, buffer strips and the like; in order to slow the velocity of flowing water and to trap pollution before it enters storm drains. There are a number of different designs that have been developed; all of these have advantages and disadvantages, which need to be evaluated to match the characteristics of each site.

Standard Urban Stormwater Management Plan

Targeting new and re-development

Public education and outreach are an important element for reducing pollution in storm water, especially when supplemented with programs to help make it easier for people to avoid polluting. Many county residents don't know that activities like washing cars and over-fertilizing lawns cause

Education and outreach

water pollution. "Drains to creek" signs on manholes and signs on public trails reminding pet-owners to clean up wastes both bring awareness to residents of their personal responsibility to watershed management. Signs naming creeks and waterways at road crossings can further raise awareness about water quality and watersheds. Free toxic roundup and disposal programs for used motor oil, paint, and other household toxics help to keep residents from pouring these on the ground or down storm drains. Residents can also be encouraged to reduce runoff from around their homes, by modifying downspout connections, slowing stormwater flows and increasing water infiltration.

Urban stormwater runoff is a classic non-point source pollution problem, but careful monitoring can help identify which storm drains produce the highest levels of pollutants. The most polluting areas can be given first priority for diversion through engineered swales, wetlands or retention basins where the water can be filtered before it reaches the Laguna's tributaries. Different parts of the watershed will also have different specific problems. Knowing whether a given drainage has, for example, high levels of nutrients or heavy metals will influence which type of water treatment will best remediate the problem. "First Flush" is volunteer-based effort for identifying such drainages, co-sponsored by the Community Clean Water Institute, Russian RiverKeeper, Sotoyome RCD, Atascadero Creek and Green Valley Creek Watershed Council, NCRWQCB, and the State of California Clean Water Team. Volunteers perform chemical monitoring at the first big storm event of the rainy season. First Flush urban stormwater data from 2002 found substantial levels of nitrogen and phosphorus, as well as residues of the pesticide Diazinon.

Volunteer-based monitoring

Rural and suburban stormwater

During storms, rapidly flowing water picks up soil and sediment from agricultural fields and construction sites, and erodes stream banks and road cuts. Bacteria and nutrients can leach into stormwater from failed septic systems. Runoff from agricultural areas is a potentially important source of sediment, nutrients and bacteria. However, compared to urban stormwater problems, substantial progress can be made by restoring riparian areas and by vigilant monitoring of road building and construction practices. A variety of effective best management practices have been developed for reducing agricultural water pollution. Programs like *Fish Friendly Farming*™ provide a standardized certification process for farmers who develop farm plans and change their practices to reduce erosion and runoff. In the past, vineyards have been a substantial source of sediment,

Fish Friendly Farming

but the County's Vineyard Erosion and Sediment Control Ordinance now requires permits from the Agricultural Commissioner's office prior to planting. Erosion-prone land is required to have erosion control plans, and major soil disturbance is prohibited during the rainy season. The Water Resources Element of the Draft General Plan 2020 calls for the development of a Sonoma County grading ordinance to reduce sedimentation.

Vineyard Erosion and Sediment Control Ordinance

Many of these changes present an economic burden for farmers, who are increasingly squeezed by narrow profit margins and broad regulations. Reauthorization of the Sonoma County Agricultural Preservation and Open Space District helps ease some of this burden, by providing a means to purchase conservation easements. The RCDs, working with the National Resource Conservation Service (NRCS), help deliver federal environmental grants for agricultural producers to undertake restoration projects. These can include fencing cattle out of creeks, planting buffer strips or hedgerows, altering drainage systems, and building roofs to cover manure piles during the rainy season. The conservation community must continue to find ways to assist private landowners with restoration projects that protect and enhance water quality.

Federal grants through RCDs and NRCS

Trash

Trash dumping is a serious problem along the rural back country roads of the Laguna. Garbage, television sets, large appliances, junked cars and old tires are frequently abandoned along roadsides and in ditches feeding directly into the main Laguna channel or its tributaries. During winter rainstorms or flood events, this trash is picked up by the stormwater, and carried directly into the streams. There are a number of different ways to address this problem. Public education campaigns can influence behavior: if county residents take more pride and personal interest in the Laguna as a public resource, they will be less likely to see it as a dumping ground. Neighborhood watch groups can monitor activities along their roads (as Sonoma County Bicycle Coalition members do), and the sheriff's department can issue citations, but it may also be necessary to consider policy changes in the fee structure for garbage dumping. Garbage tip fees are set high for several reasons. As the Meecham Road disposal facility has been closed, it is very costly to process and ship trash out of the county. Also, high fees are meant to encourage garbage sorting and recycling, which reduces the volume of trash sent to the landfill. Unfortunately, the higher the fees, the more incentive there is for illegal dumping, either along roadsides, or on private property. Other options might include: instituting a recycling and disposal tax at the time of purchase; reducing tipping fees

Influencing behavior

Other options for reducing illegal dumping for certain items; increasing the penalties for illegal dumping; or increasing the number of enforcement personnel.

Riparian restoration and wetland protection

Wetland protection and riparian restoration are essential for improving water quality into the future. A community-wide effort to restore the forested buffer areas will have a direct positive effect on water quality, as well as many indirect benefits, such as raising awareness and fostering a culture that supports environmental values. The NCRWQCB is developing a stream and wetland protection policy that recognizes the need to protect and restore the hydraulics and vegetation of riparian areas, in order to improve water quality and protect beneficial uses. The process is still in its initial stages, and policy alternatives will be shaped by public and stakeholder input. However, the process will likely result in much stronger regulation for setbacks and development along waterways, benefiting water quality. A proposal for restoring the Laguna's riparian forest is described in chapter 4.

Stronger regulation for riparian setbacks

Land use in flood-prone areas

As a general rule, it is best to restrict development in flood-prone areas. Flooding in residential and industrial areas can lead to serious water pollution as well as costly flood damage to buildings and equipment. Where flooding is unavoidable, residents and businesses should keep toxic materials (gas, oil, paint thinner, pesticides, etc…) stored well above flood elevations. Industries with a high potential for contributing pollutants to flood waters should not be located within the flood plain. Although many existing structures were sited and built at elevations above the 100-year floodplain, there are a number of reasons why flood conditions are changing in the watershed. Global climate change is predicted to increase the intensity of weather events, potentially bringing more rain in shorter time periods. Sea levels are also predicted to rise, and tidal factors already influence the height of Laguna floodwaters. Sedimentation rates are predicted to increase with human development in the upper watershed. Although sediment source control measures are currently in the evaluation and planning stages, it will be a number of years before most can be implemented; meanwhile, the Laguna floodplain continues to lose capacity. Finally, development on the Santa Rosa Plain will increase the rate of runoff, increasing the crest of flood events.

Changing flood conditions

Protecting the Laguna Subregional Wastewater Treatment Facility

The Laguna Subregional Wastewater Treatment Facility on Llano Road is the most environmentally critical and expensive structure in the floodplain. The New Year's flood of 2005–2006 came very close to inundating water treatment systems at this site. Plant operators were able to successfully treat 90 million gallons of water, to a secondary level, during the course of the flood event, but given three more inches of floodwater, the system would have been breached, spilling untreated effluent into the Laguna and shutting down the plant for an extended period of time. The Laguna Plant was sited and designed so that it would be well above the 100-year floodplain elevation, and based on all historical records the 2005/2006 event was unprecedented. Given the economic infeasibility of relocating the Laguna Plant, the uncertain potential for future flooding, and the environmental risks posed by a large sewage spill, it would be prudent to consider the construction of a levee, or other alternative, around the main treatment facility. Any such protective measures should be carefully designed, with downstream hydraulics taken fully into account, and with overall flood storage capacity being retained, as described above.

Recycled water and the IRWP

Direct discharges

Direct discharges of treated wastewater into the Laguna main channel is one of the most controversial issues in the watershed. The Laguna Subregional Wastewater Treatment Facility has the responsibility, described below, to process all of the wastewater produced by citizens of Santa Rosa, Sebastopol, Rohnert Park and Cotati, and a few unincorporated areas, amounting to several billion gallons a year. However, treatment operations are not sufficient to remove all of the nitrogen and phosphorus from the wastewater, or a number of low molecular-weight organic compounds and dissolved metals. In the past, the volume of Laguna discharge has been based on the flow rates of the Russian River. When the river is high, regulations have allowed direct discharges to the Laguna—irrespective of the Laguna's own water levels—resulting in periodic pulses of wastewater forming a high percentage of the Laguna's total water volume.

Tertiary treated water

In the treatment process, sewage is passed through a series of filters and bacterial treatments to remove trash and organic wastes. The water is then exposed to UV radiation to eliminate remaining viruses or pathogens, reaching a "tertiary treated" level which is considered clean enough for physical contact. The IRWP, or Incremental Recycled Water Program, is the Subregional System's plan for disposing treated wastewater through 2020. In developing this program, the Subregional System has analyzed economic costs and environmental impacts for a range of disposal, reuse and reduction options to meet current needs and projected growth. The final plan incorporates five of these options: 1) indoor water conservation, 2) urban reuse—mainly irrigation, 3) agricultural reuse—mainly irrigation, 4) Geyser's expansion—using wastewater to generate electricity by recharging steam fields, and 5) discharge to the Russian River. Having all five of these components in the plan is intended to allow enough flexibility to accommodate different weather conditions and future regulatory changes.

IRWP options

The Subregional System's stated objectives are to provide the wastewater treatment capacity necessary to accommodate the projected population growth; to operate the system in a way that protects public health and natural resources, to promote the use of recycled water; to meet existing regulatory requirements and provide flexibility to meet future regulations; and to accomplish all of these objectives in a manner that is economically feasible. The most direct ways that the IRWP affects the Laguna are through continuation of the agricultural irrigation program, through direct discharge into the Laguna, and by providing the potential for constructed wetlands.

Accommodating population growth and protecting public health

Agricultural and urban irrigation and re-use

Agricultural irrigation and urban irrigation are perhaps the highest and best uses for treated wastewater. Plants and their associated soil microorganisms are well adapted to remove residual nutrients and organic compounds left after the treatment process. Using wastewater reduces the demand for groundwater, and helps sustain a farm economy in the Laguna, which in turn has benefits for long-term food security, cultural continuity, and maintaining open space. The negative aspects of agricultural irrigation are that it favors non-native plant species and can interfere with oak recruitment and longevity. Other concerns have been raised about the potential for faulty irrigation systems creating polluted dry-season runoff, and increasing the opportunities for vineyard conversion in otherwise marginal areas. It is possible to reduce the problematic aspects of irrigation on natural areas by setting aside portions of the Laguna, especially around historic seasonal wetlands, removing these areas from irrigation, and restoring them to native grass landscapes. Instituting best management practices (BMPs) can help insure irrigation levels are within grassland absorption capacity and that agricultural operations minimize run-off. When the existing irrigation program began, farmers were initially reluctant to accept treated wastewater, so they were paid incentives to use wastewater for irrigation, but since the Geyser's expansion came

Sustaining a farm economy

on line in 2004, wastewater has been in tighter supply, and the incentive program has been discontinued.

Storage and distribution

The primary barrier to expanding irrigation and re-use of treated wastewater is the need for storage and distribution networks. A large proportion of the wastewater is generated in the winter months, when there is no need for irrigation. This water must be stored in large ponds before being pumped to the end-user. Existing ponds do not have the capacity to accommodate a large number of new users, so more ponds would need to be constructed before expanding this use. Large agricultural producers can afford to set aside land to build their own water storage ponds, but new ponds near the cities would have to be constructed, possibly by developers, possibly with public funds, before initiating urban re-use programs. Locating and constructing new holding ponds will require extensive permitting and environmental impact reports. Because of health codes, urban users would have to install "purple" double plumbing, to keep wastewater from being used for regular domestic purposes. While this may be feasible for new construction, it will likely be too expensive to retrofit existing homes. In the long term, irrigation and re-use, along with water conservation, are the most sustainable solutions for wastewater disposal, and alleviate many of the concerns about residual pollutants entering the Laguna's waterways.

Re-use and conservation

Concerns have been raised about the wisdom of transporting treated wastewater for re-use in other watersheds, such as Alexander Valley. A great proportion of the water that is processed by the plant was pumped from wells along the Russian River near Forestville. This water presumably originated in higher reaches of the Russian and its tributaries or in the Eel River before being diverted into the Russian. Some water is pumped from wells located on the Santa Rosa Plain, and other water enters the treatment system through infiltration and inflow (I&I)—where subsurface groundwater flows into leaky pipes. Strict budgeting and re-apportioning water for re-use is possible, but the re-use process is likely to be dominated by logistical and direct environmental impact considerations for the near future.

Water budgeting

Wastewater Discharge

Historically, treated wastewater has been disposed of by discharging it directly into the Laguna at several outlet points between the Llano Road treatment plant and Delta Pond, just south of the confluence with Santa Rosa Creek. To meet tightening restrictions, the IRWP proposes to reduce or eliminate discharge into the Laguna, and instead to pipe the water north to discharge into the Russian River. This could be done either by

Discharge proposals

directly pumping treated water into the river, or by releasing it indirectly through percolation ponds, basins, or injection wells. Indirect discharge may be favored because it will probably have less water-quality permit requirements: passage through soil layers polishes the water of most remaining impurities, and it avoids problems associated with discharging warm water. Wastewater discharges are regulated by a National Pollution Discharge Elimination System (NPDES) permit from the NCRWQCB.

California Toxics Rule and priority pollutants

Some of the restrictions and discharge monitoring requirements are based on the newly adopted California Toxics Rule (CTR). The State Water Resources Control Board mandates that the concentration of listed "priority" pollutants in receiving waters (e.g., the Laguna) can never exceed set limits. The toxins of most concern for the Laguna, based on prior testing, are copper, lead, nickel and cyanide. In other words, any spike in the concentration of these compounds in the wastewater must be sufficiently diluted by the water volume of the Laguna. To comply with CTR, these compounds can be removed with an Advanced Membrane Treatment (AMT), or the system may discharge at lower volumes. The AMT is very expensive, but is the only effective way to remove metals from the wastewater, and may also remove nutrients. To meet these goals, Laguna discharge sites may be limited to Meadow Lane and Delta ponds. The Meadow Lane discharge occurs near the confluence of the Laguna and Colgan Creek, and the Delta discharge is at the confluence of the Laguna and Santa Rosa Creek. The combined flows at these sites give the greatest opportunities for dilution. The permitted discharge season is from October 1–May 14, but the timing of actual discharges depends on the flow volume of the Russian River.

Advance Membrane Treatment versus dilution

Although the CTR is a strong regulatory reason for changing Laguna discharge practices, nutrients in the wastewater are a greater concern to most citizens involved in water quality issues. While wastewater is just one of a number of nutrient sources, the rank abundance of nuisance plant growth and low dissolved oxygen in the Laguna channel are a strong argument for reducing excess nutrients from all sources. Direct discharges of wastewater to the Laguna should be phased out as soon as possible. In the interim, proposed limits on nutrient concentrations for receiving waters will help to limit the percent volume of discharge to a lower fraction of the Laguna flow. Until the phase-out can occur, the Subregional System should restrict discharges to November-February to avoid discharging during active growth periods of *Ludwigia* and other aquatic weeds.

Direct discharge phaseout

Constructed Wetlands

Constructed wetlands are a secondary part of the IRWP. They do not remove metals, so they don't help the Subregional System meet the conditions of the CTR. Wetlands remove nutrients, but tend to increase temperature and pH, making it more difficult to comply with water quality regulations for those impairments. The constructed wetlands at Kelly Farm are on par with the efficiency of irrigated hay fields for disposing of wastewater through evaporation and transpiration. However, since the Geysers began taking wastewater, summer irrigation water has been in high demand, and additional wetlands would compete with this water use. At this time, the IRWP considers wetlands to be an optional component for habitat enhancement and mitigation. These would be located near the IRWP pipelines or adjacent to existing storage facilities. Nonetheless, constructed wetlands are considered a BMP for stormwater treatment in the SUSMP, and this is an important area for further study and planning.

Relationship to Stormwater

Total Maximum Daily Load (TMDL) plans generally set a regulatory limit on the total amount of nutrients allowed from all sources. This motivates the Subregional System to support programs to limit nutrients and other pollutants entering the system via stormwater or run-off from agricultural operations. If ambient nutrient levels increase, the Subregional System will have tighter restrictions on the levels of nutrients in wastewater discharges. Currently, it is estimated that close to 20% of the water treated by the Subregional System comes from subsurface groundwater flow that leaks into the pipes on the way to the treatment plant (called "infiltration and inflow" or I&I). There are studies underway to determine which sections have the highest infiltration, and would most benefit from upgrades; the findings of these studies to-date leave too many unanswered questions and were not included in the IRWP.

Subsurface infiltration and inflow

Assessment

Although there are many unanswered questions about the best way to restore the Laguna watershed's hydrology, hydraulics and water quality, there are also a number of potential areas for progress to be made. To a great extent, riparian systems are self-restoring. Part of the challenge is to understand how to complement and facilitate these natural processes while accommodating human infrastructure. Water quality concerns are in many ways inseparable from flood control, sedimentation and other hydrological issues. For all of these, the most important task is to initiate rigorous baseline assessments of the watershed and to develop predictive models for use in environmental and urban planning.

Principal sources

Circuit Rider Productions, Inc. 2003. "Riparian Habitat Restoration" In: *California Salmonid Stream Habitat Restoration Manual*. CDFG. (http://www.dfg.ca.gov/nafwb/pubs/2004/CDFG_manual_XI_final.pdf).

Hayhoe, Katharine; et.al. 2004. *Emissions pathways, climate change, and impacts on California*. PNAS 101 (34): 12422-12427.

Philip Williams & Associates, Ltd. 2004. *Sediment Sources, Rate & Fate in the Laguna de Santa Rosa, Sonoma County, California*. Report for the Sonoma County Water Agency and the U.S. Army Corps of Engineers.

Riley, Ann L. 1998. *Restoring streams in cities: a guide for planners, policy makers and citizens*. Island Press.

Riley, Ann L. 2003. *A primer on stream and river protection for the regulator and program manager.* Technical Reference Circular W. D. 02-#1. San Francisco Bay Region, California Regional Water Quality Control Board. Available online at the website of Marin County Stormwater Pollution Prevention Program (MCSTOPP) (http://www.mcstoppp.org/)

Sonoma County Flood Control and Water Conservation District (SCFCWCD). Ca.1965. *Flood!! December 1964-January 1965, Santa Rosa*.

Sonoma County General Plan 2020. (Draft accessed March 2006). Public Safety Element. Sonoma County Permit and Resource Management Department. Santa Rosa, CA.

Zedler, Joy B. and Suzanne Kercher. 2004. "Causes and consequences of invasive plants in wetlands: opportunities, opportunists, and outcomes," *Critical Reviews in Plant Sciences* 23(5): 431–452.

Supplemental sources

CH2MHill. 2004. *Recycled Water Master Plan. Incremental Recycled Water Program*. Prepared for the City of Santa Rosa. (http://www.incrementalrecycledwaterprogram.com).

Community Clean Water Institute. 2004. *Laguna de Santa Rosa 2004 Data Report*. (www.ccwi.org).

EOA Inc., BFK Engineers. 2005. *Standard Urban Stormwater Mitigation Plan*. Prepared for the County of Sonoma, the City of Santa Rosa, and the Russian River Watershed Assn. Guidelines available on line at: (http://ci.santa-rosa.ca.us/default.aspx?PageId=319).

Harris, Richard and Susie Kocher. 2001. *Summary of Sonoma County policies relating to anadromous fish habitat conservation*. Excerpted from: *Effects of county land use policies and management practices on anadromous salmonids and their habitat*. UC Berkeley Extension. Accessed on line (October 2005): (http://fishnet.marin.org/pdf/sonoma_policy_summary.pdf)

Jackson, T.A. 1988. "Methyl mercury levels in a polluted prairie river-lake system: seasonal and site-specific variations and the dominant influence of trophic conditions" *Canadian Journal of Fisheries & Aquatic Sciences*. 43(10): 1873-1887.

Lewis, D.J., Atwill, E.R., Lennox, M.S., Hou, L., Karle, B. and K.W. Tate. 2005. "Linking on-farm dairy management practices to storm-flow fecal coliform loading for California coastal watersheds" *Environmental Monitoring and Assessment* 107: 407-425.

Nicholson, Dave, and Michael Murphy. 2004. *Assessment of Best Management Practices for equestrian facilities in the Tomales Bay watershed*. Marin County Stormwater Pollution Prevention Program (MCSTOPP).

North Coast Regional Water Quality Control Board. 1993. *Basin Plan*. http://www.waterboards.ca.gov/northcoast/programs/basinplan/basin.html.

Opperman, J. J., and A. M. Merenlender. Aug 2004. "The effectiveness of riparian restoration for improving instream fish habitat in four hardwood-dominated California streams." *North American Journal of Fisheries Management* 24(3):822–834.

Roni, P., T.J. Beechie, R.E. Bilby, F.E. Leonetti, M.M. Pollock, and G.R. Pess. (2002) "A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific

Northwest watersheds" *North American Journal of Fisheries Management* 22: 1-20.

Smith, David. 1990. *History, Land Uses and Natural Resources of the Laguna de Santa Rosa*. Prepared of behalf of the Santa Rosa Subregional Water Reclamation System.

Wickham, Daniel. 2000. *Phosphate loading and eutrophication in the Laguna de Santa Rosa*. Report to the Russian River Watershed Protection Committee and the City of Santa Rosa.

For more information

Community Clean Water Institute.
http://www.ccwi.org

National Resource Conservation Service.
http://www.ca.nrcs.usda.gov/programs/

Russian River Interactive Information System.
http://www.russianriverwatershed.net

Fish Friendly Farming.
http://www.fishfriendlyfarming.org