Indicators 7

7.1 Recommendations

The Laguna model development project is recommending the use of indicators for future monitoring and modeling assessments. Indicators are measurable components of the ecosystem that are linked to both stressors and desired outcomes. Indicators tell the user something about the status of the Laguna either in progress towards mitigating a stressor or the status of a Beneficial Use (or another desired outcome). Indicators are consistent with the emerging California Nutrient Numeric Endpoints framework that is being used to develop targets for nutrient TMDLs in EPA Region IX. Developing and monitoring a set of indicators is the primary tool for establishing hydrologic, geomorphic, and water quality conditions, as well as ecosystem health. Indicators also serve in evaluating the performance of any future studies and guide monitoring recommendations to document achievement of management goals and desired conditions.

The indicators described in the following sections were selected through the application of the overview conceptual models for hydrology, water quality, and ecosytem to identify factors that are intermediate measures (response variables C-G) between stressors and Beneficial Uses. Each indicator is briefly described including its linkage to stressors and endpoints and a recommendation is provided for communicating its status (*i.e.*, metric). This section includes more indicators than can be practically incorporated into the Laguna de Santa Rosa stewardship framework. Additional interaction among participating agencies and stakeholders is needed to prioritize and to develop a monitoring program for each indicator that is adopted in the final list.

Hydrologic indicators in the Laguna watershed are limited due to its unusual lake-like stream characteristics and its interaction with the Russian River. One management goal of our hydrologic conceptual model is related to flood hazards. Due to the complexity of hydrologic conditions in the Russian River and the Laguna, and hydraulic interactions at their confluence, there are no hydrologic indicators that would quantify future change in flood elevations. Any meaningful comparison of past, current or future flood elevations in the Lower Laguna require that base level conditions (that is, water surface elevations in the Russian River) be the same for the event considered. In view of the stochasticity in precipitation and runoff events in both watersheds, comparability of flood conditions "all things being equal" is not feasible. Therefore, we are not recommending an indicator to identify flood elevations in the Lower Laguna. The recommended hydrologic and geomorphic indicators are selected to accomplish the following:

- To identify the changes in flood frequencies
- To document rapid geomorphic or habitat evolution that appears to be driven by changed or changing hydrologic or hydraulic conditions

The water quality and ecosystem indicators include several parameters that will be critical to the development of a TMDL for the Laguna. Several parameters are also already being evaluated through various programs (*e.g.*, *Ludwigia*) or have existing information and analyses that need to be supplemented (*e.g.*, nutrient concentrations, DO, and temperature).

A list of suggested general hydrologic, geomorphic, water quality, and ecosystem health indicators is provided below:

- High and low frequency flood flows / hydrographs: 2-year and 100-year flood
- Channel and floodplain cross sections
- Longitudinal channel profiles
- Bankfull flow
- Rates of bed and bank erosion or aggradation
- Dredge removal quantities
- Macrophytes (extent of Laguna with density above a selected threshold value)
- Chlorophyll a
- Minimum DO/% Saturation
- Temperature/temperature stratification
- Sediment indicator (not currently defined)
- Benthic macro-invertebrates diversity index (look at storm water data)
- Warm Water Fish – resident species
- Unionized ammonia/pH
- Nutrient concentrations in tributaries and main channel
- Organic carbon/BOD concentrations in tributaries and main channel
- Habitat condition
- Amphibians
- Birds

Each of these indicators is described in the following sections. Additional information will be provided regarding the measurement and interpretation of the proposed indicators in the monitoring recommendations as part of the final project report.

7.2 High and low frequency flood flows

We are recommending the use of both high frequency and low frequency flood flows as indicators of hydrologic change in the watershed. The 2-year flood event volume and the 100-year flood event volume are recommended as hydrologic indicators. The 2-year flood event is the flood event that has a 50 percent chance of being equaled or exceeded in any given year (or occurs on the average once every 2 years). The 100-year flood event is the flood event that has a 1 percent change of being equaled or exceeded in any giver year. The 2-year flood event is a high frequency, low magnitude event that has a considerable volume and occurs often enough to affect channel geomorphology. The variation in the 2-

year event volume over time can be used an indicator of hydrologic change. The 100-year flood event volume is recommended to represent low frequency, high magnitude events in the watershed. The 100-year flood event is FEMA's standard flood for floodplain management and flood insurance. An alternative is to compare hydrographs instead of flows which would allow comparisons of peak flow rates, time to peak, duration of flow above sediment transporting velocities and cumulative impacts from combining changes in hydrographs of tributary streams, in addition to total flood volume. Hydro graphs would allow the use of several metrics to represent the high and low frequency flood flows.

Metric – The measure of flood event volume is acre feet.

7.3 Channel and floodplain cross sections

Channel and floodplain cross sections represent the channel's ability to transport water and sediment. Variation in channel or floodplain cross sections would indicate change in overall storage capacity. Temporal variation in cross sections locations would also identify locations and magnitudes of degradation and aggradation and would indicate channel stability over time.

Metric – Cross sections are measured in length units (feet or meter).

7.4 Longitudinal channel profiles

Longitudinal profile is simply a plot of height against distance downstream. It represents the gradient of a stream at the reach or watershed scale. A profile would reveal overall geomorphic characteristics of a channel and would indicate potential erosion/ deposition zones. It is also a general indicator of sediment transport capacities along a channel because gradient strongly affects transport capacity. Variation in longitudinal profile would point to adjustments in channel gradients that can be brought about by aggradation, degradation, or changes to channel sinuosity. The process of aggradation and degradation often operates in response to changes in watershed controls or base level.

Metric – Longitudinal profiles are measured in length units (feet or meter).

7.5 Bankfull flows

Bankfull discharge is the flow of water that fills the channel and just begins to overtop the streambank in to the floodplain. River channels adjust on average to bankfull discharges which have enough stream power to erode, transport, and deposit the materials transported from upstream or contributed by banks. Bankfull discharge is commonly equated to the 2-year flood because a significant number of studies of statistical hydrology and geomorphic form in different environments have frequently found the 2-year flow (more specifically flows ranging from 1.0- to 2.5-years) to coincide with bankfull discharge. Variation in bankfull discharge is an indicator of channel geomorphic change that would point to either aggradation or degradation in the system.

Metric – The metrics for bankfull flows is discharge units in cubic feet per second or cubic meters per second.

7.6 Bed and bank erosion or aggradation

Land use modifications and changes in watershed conditions upset the continuity of sediment transport resulting in either degradation or aggradation. Degradation reflects bed load starvation and aggradation reflects excessive bed load input. Rates of bed and bank erosion or aggradation are indicators of geomorphic change due to land use modifications in the short term. Specifically they would indicate changes in sediment supply and storage capacity. Superimposed with flood volumes, they could be used to derive implications for flood storage capacity

Metric – Bank erosion can be expressed in terms of retreat rate, which is measured in length unit over time (such as feet per year). Bed erosion or aggradation is represented by change in bed elevation and is measured in feet per year or meter per year (or longer time frame).

7.7 Dredge removal quantities

Flood control channels in the Laguna watershed are periodically dredged. The dredged sediment volumes would indicate the magnitude of aggradational processes in the lower watershed. Aggradation in turn is an indicator of sediment supply characteristics or variations and is linked to flood elevations.

Metric – Dredge volumes are expressed in acre feet or cubic yard over a specified distance expressed in feet or meter.

7.8 Macrophytes

Macrophytes are rooted emergent, submergent, or floating aquatic plants (*e.g.*, *Ludwigia* sp.) that grow in or near water. Macrophytes provide cover for fish and substrate for aquatic invertebrates and are so beneficial to lakes. They produce oxygen, which assists with overall lake functioning, and provide food for some fish and other wildlife. Crowder and Painter (1991) indicate that a lack of macrophytes in a system where they are expected to occur may suggest a reduced population of sport and forage fish and waterfowl. Macrophytes can affect the designated uses of water and be ecologically important habitat. High densities of macrophytes caused by excess nutrient enrichment can impact recreational uses, such as swimming and boating, and also degrade the aesthetic value of the resource. Ecologically, an increase in macrophyte cover can provide necessary habitat for aquatic life in streams. However, decomposition and nocturnal respiration can cause oxygen depletion and low reaeration rates. Even relatively small reductions in dissolved oxygen can have adverse effects on both invertebrate and fish communities, and aerobic conditions can alter a wide range of chemical equilibria, and may mobilize certain chemical pollutants as well as generate noxious odors. Nuisance levels of macrophytes also reduce stream flows resulting in increased sedimentation and, ultimately, reduced fish spawning habitat. In addition, the absence of macrophytes may also indicate water quality problems as a result of excessive turbidity, herbicides, or salinization.

Metric – Macrophytes are excellent indicators of watershed health. They respond to nutrients, light, toxic contaminants, metals, herbicides, turbidity, water level change, and salt. They are easily sampled through the use of transects or aerial photography, and do not require laboratory analysis. They are easily used for calculating simple abundance metrics, and are integrators of environmental condition (USEPA 2006). The measure of aquatic macrophyte density is the percent of aerial coverage by channel reach.

7.9 Chlorophyll-a

Chlorophyll a is the photosynthetic pigment that plants use to produce cell material from sunlight and carbon. The amount of chlorophyll-a in the water column or on the substrate is a measure of phytoplankton (aquatic algae) biomass and, therefore, it is an indicator of water quality. Phytoplankton form the base of the Laguna food web and provide food for fish and other filter-feeding organisms. Changes in abundance, species composition, and productivity of phytoplankton are commonly the first biological response to nutrient enrichment and are a measure of the effectiveness of nutrient reduction strategies. These changes in phytoplankton influence the food webs of which they are a part and the fisheries that depend upon them. Too much phytoplankton, caused by overproduction and/or under-consumption, reduces water clarity and depletes oxygen in bottom waters.

Metric – The measure of chlorophyll-a in the watercolumn is micro-grams chlorophyll-a/liter water. The measure of substrate chlorophyll-a is mg chlorophyll-a/unit area.

7.10 Dissolved oxygen/percent saturation

Dissolved oxygen (DO) concentration and percent saturation in water are often used to gauge the overall health of the aquatic environment. The dissolved oxygen concentration and percent saturation are intricately linked to algal concentrations in the waterbody as well as the decomposition of organic material. When excessive amounts of algae die and sink to the bottom, bacteria decompose the material and consume oxygen. This increase in activity results in increased oxygen consumption and can deplete available oxygen. Additionally, dissolved oxygen levels change throughout the 24-hour day/night cycle, with greater concentrations being found during the day while photosynthesis is taking place and lower dissolved oxygen levels available during the night-time when respiration is taking place. As such, point measurements of dissolved oxygen are not sufficient to assess this indicator and continuous measurements are required.

Low oxygen levels generally affect bottom waters first and most severely and can result in reducing conditions within the sediments, which may cause previously bound nutrients and toxicants to be released into the water column.

Generally, dissolved oxygen concentrations above 5 mg/L are protective of most aquatic life uses. However, cold-water fishes require higher DO concentrations as do all species in stages of early development.

Metric – Dissolved oxygen concentration and percent saturation are measured by continuous reading electronic probes. The units of measurement are mg/l (concentration) and percent (saturation.)

7.11 Temperature

Stream temperatures are the net result of a variety of energy transfer processes, including radiation inputs, evaporation, convection, conduction, and advection. Stream temperatures reflect both the seasonal change in net radiation and daily changes in air temperature.

Increased temperatures are known to increase biological and chemical activity and controls the amount of dissolved oxygen that a waterbody can contain, drives certain equilibrium reactions, for example the equilibrium between ammonium and ammonia, both being toxic to aquatic life. Stream temperatures can also form a thermal barrier to anadromous cold water fish populations that use the Laguna during their seasonal migration to the colder upper reaches of the waterbody.

Metric **–** Temperature can be measured by either a thermometer or an electronic sensor and should be monitored continuously at the surface and bottom of the Laguna.

7.12 Sediment

Increased sediment load can greatly impair, or even eliminate, fish and aquatic invertebrate habitat, and alter the structure and width of the streambanks and adjacent riparian zone. Fine sediment can impair the use of the water for municipal or agricultural purposes. Many nutrients and other chemical constituents are sorbed onto fine particles, so sediment loads are often directly related to the load of these constituents. Indirect effects of increased sediment loads may include increased stream temperatures and decreased inter gravel dissolved oxygen.

Metric **–** The primary metrics of this indicator are sediment grain size, total organic carbon, nutrients, and stream embeddedness. Secondary metrics of this indicator are total nitrogen and total phosphorus.

7.13 Benthic macroinvertebrate diversity index

Benthic macroinvertebrates have several characteristics which make them potentially useful as indicators of water quality. First, many macroinvertebrates have either limited migration patterns or a sessile mode of life, and this makes them well suited for assessing site-specific impacts. Second, their life spans of several months to a few years allow them to be used as indicators of past environmental conditions (Platts et al., 1983). Third, benthic macroinvertebrates are abundant in most streams. Fourth, sampling is relatively easy and inexpensive in terms of time and equipment (USEPA 1989). Finally, the sensitivity of aquatic insects to habitat and water quality change often make them more effective indicators of stream impairment than chemical measurements (USEPA, 1990).

Metric **–** The primary metrics of this indicator are abundance, species richness, diversity indices, and biotic indices.

7.14 Warm water fish

Fish are a useful surrogate or integrator of a variety of physical and biological factors. Some of the factors necessary to sustain or restore a particular fish population include 1) adequate streamflow (*i.e.*, water depth and habitat space), 2) sufficient spawning habitat, 3) sufficient rearing habitat, 4) appropriate food sources at different life stages, and 5) proper environmental conditions (particularly temperature, dissolved oxygen, and turbidity). Fish permanently live in the water throughout their life, vary in their tolerance to amount and types of pollution, are straightforward to collect with the right equipment, live for several years, and are easy to identify in the field. Most fish continually inhabit the receiving water and integrate the chemical, physical, and biological histories of the waters. Fish have been used worldwide for many years to indicate clean or polluted waters, and whether conditions are doing better or getting worse.

Metric **-** The primary metrics of this indicator are the presence or absence of a particular species, numbers of a particular species, or community parameters such as productivity, density, and diversity. Fish health clearly indicates toxicity and allows assessment of root-causes (USEPA 2006). Therefore, a variety of test species should be incorporated into bioassays due to varying tolerances to specific toxins (Salop 2002).

7.15 Unionized ammonia/pH

Unionized ammonia (NH_3) is an intermediate breakdown product of organic nitrogen, fertilizers, and animal wastes. Ammonia is extremely toxic to fish and invertebrates at concentrations as low as 0.002 mg/l. The concentration of unionized ammonia in aquatic systems is driven by pH and temperature. As such, conditions that cause the temperature to rise (e.g., increased sediment load, turbidity); the pH to rise (e.g., increased CO_2 consumption during photosynthesis); or increased ammonia production (e.g., decomposition of organic material) will also cause an increase in unionized ammonia.

Metric **–** The primary metrics of this indicator are total ammonia-nitrogen (mg/l), pH, and temperature. Since pH is influenced by the algal photosynthesis:respiration cycle and changes over a 24-hour period (*i.e.*, lower pH's during the evening respiratory cycle and higher pHs during the daytime photosynthetic cycle), the unionized ammonia concentrations should be monitored continuously.

7.16 Nutrient concentrations

While nutrients (nitrogen and phosphorus) are not generally directly toxic to aquatic life, they can stimulate the growth rates of algae and macrophytes as well as the activity rates of bacteria and fungi. Excess growth of algae, macrophytes, bacteria, and fungi can result in excessive growth and a resultant over consumption of dissolved oxygen. They can also negatively affect the aesthetic quality of the waterbody and impair contact and non-contact recreational beneficial uses.

Metric – All species of nitrogen (nitrate, nitrite, particulate and dissolved organic nitrogen, TKN, total N) and all species of phosphorus (phosphate, particulate and dissolved organic phosphorus, total phosphorus) should be monitored. So that nutrient loadings can be estimated, all inputs into the Laguna should be monitored (*e.g.*, tributaries, stormwater outfalls, etc.)

7.17 Organic carbon concentrations / BOD

Biological/biochemical oxygen demand (BOD) is the amount of oxygen consumed by biota in water. It is a measure of the portion of organic carbon that is relatively easily oxidized by micro-organisms. It is used as an indicator of dissolved organic carbon. As such, both organic carbon and BOD loadings from both terrestrial and aquatic ecosystems are potential sinks for dissolved oxygen.

Metric - Dissolved and total organic carbon (%) and 5-day BOD (mg/l) should be monitored so that nutrient loadings can be estimated. All inputs into the Laguna should be monitored (*e.g.*, tributaries, stormwater outfalls, etc.)

7.18 Habitat condition

Plants play a crucial role in invertebrate and vertebrate community diversity by providing habitat structure and essential food sources. Besides their crucial position at the food web base, the diversity of plant species, ages, shapes and sizes defines structural variety which in turn boosts the diversity of birds and other vertebrates and invertebrates (Kreitinger & Gardali 2007). Diverse vegetation structure creates a mixture of habitat niches for organisms to utilize within a given plant community, e.g. insects feed on plants and then provide nourishments to birds, which are preyed upon by other birds or mammals. Plants provide nesting sites for birds or mammals and provide shade and spawning sites for amphibians and fish along waterways. Vertical structure of vegetation ensures that bottom as well as canopy dwellers find cover and foraging habitat within a heterogeneous habitat matrix.

Riparian and oak woodlands also improve water and air quality, absorb water runoff and slow water velocity along streams. Riparian zones support a disproportionately large amount of biodiversity compared to other landscape elements (Harris et al 1996). Terrestrial areas surrounding wetlands and streams are core habitats for many terrestrial, aquatic and semi-aquatic species (Demilitsch and Bodie 2003). Riparian zones also function as important corridors for longer-range animal movement, making riparian zones one of the most important landscape elements for biodiversity (Hilty et al 2006).

Areas where historical riparian vegetation has been lost are thus sure indicators of habitat loss/degradation, negatively affecting the entire associated aquatic and terrestrial communities. Terrestrial streamside communities are mainly impacted through the loss of cover, foraging and nesting habitat (Pearson and Manuwal 2001). Stream habitat degradation could be in the form of increased run-off and stream bank erosion, lack of shade along stream banks causing increased water temperatures, and loss of fish cover or spawning habitat. Lack of riparian vegetation may also allow adjacent livestock to enter the water, causing bank erosion, degrading the stream bottom through trampling and the introduction of increased nutrients into the stream via direct and indirect input of livestock excrement.

The loss or degradation of vegetation along streams also reduces the effectiveness of riparian buffers to improve water quality through processing and removal of excess anthropogenic nitrogen from surface and ground waters. To maintain maximum buffer effectiveness, buffer integrity should be protected against soil compaction, loss of vegetation, and stream incision (Mayer et al 2006). Restoring degraded riparian zones, and stream channels may improve nitrogen removal capacity of the stream system, making riparian buffers a 'best management practice' (Mayer et al 2006). While there is not one generic riparian corridor width to keep water clean, stabilize banks, protect wildlife, and satisfy human demands, generally the larger the width of vegetation, the better the impact on ecosystem services and biodiversity (Kreitinger & Gardali 2007, Semlitsch and Bodie 2003, Pearson and Manuwal 2001).

As exotic invasive plants, such as invasive *Ludwigia* sp., increasingly take hold in native plant communities, they threaten native biodiversity by changing the native vegetation structural diversity, often completely 'taking over,' and in some cases as "ecosystem engineers" (Crooks 2002) not only out-competing native plants and establishing an extensive and expanding mono-culture, but in the process permanently changing the habitat structure and function. This process so fundamentally changes the original native ecosystem, causing the local extinction of organisms tightly linked to the original community structure and function (National Invasive Species Council 2001). Most invasive plants were brought in by humans and initially established in disturbed sites.

Profound plant community changes can occur due to numerous anthropogenic factors. A community's ecosystem services such as preventing soil erosion and keeping water clean, may be reduced by development, over-harvesting of forest trees, trampling, unsustainable farming practices, nearby infrastructure, urban runoff, etc. Once plant community structure has been altered, e.g. from high canopy forest to non-native annual grassland, the capacity of the system to hold on to top soil and to decrease run-off has diminished so that soil erosion rates will increase measurably (SEC 2006).

***Metric* -** Habitat condition can be measured by measuring vegetation, woody debris, exotic vegetation conditions and the width and continuity of habitat corridors.

7.19 Amphibians

Frogs and other amphibians are well known for their sensitivity to pollution and habitat degradation (Welsh and Ollivier 1998). They need a healthy environment, both on land and in water, to complete their life cycle from egg to larva to adult. Polluted water that may contain chemicals such as fertilizers or detergents can significantly negatively impact amphibian populations, and so have reduced amphibian populations worldwide. Pollutants commonly result in the death of the eggs or larvae, but may result in the production of abnormalities of soft and/or skeletal tissues that can later be seen in the adult frog (Howe et al 1998). Chemical synergy and life-stage sensitivity should always be addressed to properly assess the toxicity of herbicides or other chemicals to non-target organisms (Howe et al 1998).

***Metric* -** Amphibian eggs and larvae appear more sensitive to pollution or environmental change than adult amphibians or fish, making them excellent indicators of environmental toxicity (Howe et al 1998).

7.20 Birds

The usefulness of birds as indicators of ecosystem integrity has been widely discussed (e.g., Blus & Henny 1997, Temple and Wiens 1989, Morrison 1986, Reichholf 1976). The factors that make birds attractive as indicators of wetland integrity include their ease of monitoring (usually without samples to process). Their identification is simple, allowing capable non-scientists to assist with surveys, and so birds are suited for relatively easy *in situ* assessments (confined or behaviorally imprinted individuals), and established survey protocols are easily available. Because of their position at the top of food chains some bird species (e.g., many raptors and wading birds) have a tendency to accumulate toxic substances in their tissue over time. Birds have a longer life span than other bio-indicators, which may make them more sensitive to some cumulative impacts and more able than other groups to integrate the effects of episodic events. The only extensive nationwide databases that exist on trends, habitat needs and distribution—as well as the availability of moderately extensive bioassay databases—are for birds (USEPA 2006).

Birds can serve as indicators of hydrologic factors, changes in vegetative cover, sedimentation and turbidity, and pesticide and heavy metal contamination. Considering the current availability of data and tested protocols, birds are the only taxonomic group capable of serving as bio-indicators on a regional scale. While birds are likely to be poor indicators of the integrity of a specific wetland, their trends in species composition and relative abundance when measured throughout a region can integrate changes occurring in wetlands across the region. (USEPA 2006).

Birds as indicators of hydrologic factors

Hydrologic changes affect birds both directly and indirectly. Present water depths of the wetland can be indicated by the assemblage of breeding birds that have established nesting sites. For example, the regular presence of certain diving ducks and western grebes can indicate relatively deep water (> 2 m) and consequently, the likely seasonal persistence of water in an individual wetland (Fredrickson and Reid 1986). Species that are likely to be the most sensitive indicators of water levels might be those that (a) nest along water edges, (b) feed on mudflats (e.g., shorebirds), (c) require a particular combination of wetland hydroperiod types in a region (e.g., Kantrud and Stewart 1984). In contrast, species (e.g., marsh wren, some diving ducks) that characteristically nest well above the water level might be less directly vulnerable, and thus are probably weaker indicators (USEPA 2006).

Birds as indicators of changes in vegetative cover

Birds mostly respond strongly to changes in vegetation density and type, both within wetlands (Weller and Spatcher 1965, Lokemoen 1973) and in the surrounding landscape (Huber and Steuter 1984). Many studies have shown that reduced reproductive success in waterfowl can be a strong indicator of loss of cover in a wetland or surrounding landscape due to grazing, herbicides, cultivation, or other factors (e.g. Dwernychuk and Boag 1973).

Birds as indicators of sedimentation and turbidity

Bird species (e.g., redhead) that feed on submersed plants are likely to be affected the most by turbid conditions in wetlands. At a regional level, changes in the occurrence, frequency, or range sizes of such species might indicate overall trends in turbidity and sedimentation (USEPA 2006).

Birds as indicators of pesticide and heavy metal contamination

Declines in avian richness, and perhaps density and biomass, would be expected at wetland complexes or regions heavily contaminated by pesticides or heavy metals. Many studies have documented birds failing to reproduce or grow successfully in wetlands severely contaminated with heavy metals (e.g., Scheuhammer 1987) and particular pesticides, e.g., phorate. Selenium levels of > 0.050 mg/L, or > 0.030 mg/g of body weight, pose a potential risk to many waterbird species because selenium is rapidly accumulated in food chains and body tissues (USEPA 2006). Incidences of organochlorines, PCB's, and mercury accumulating in birds, especially raptorial and fish-eating species, have been reported (Weseloh et al 1997).

Physical condition, deformities, behavior

Eggshell thinning, physical deformities of embryos and hatching birds, and feather loss in adult birds, are symptoms of severe contamination of wetland food chains with certain chemicals, such as selenium (Scheuhammer 1987, Ohlendorf et al. 1990). Drooping wings and abnormal neck posture can indicate poisoning by carbamate or organophosphate insecticides.

Biomarkers in birds

The USFWS's Biomonitoring of Environmental Status and Trends (BEST) program has proposed use of several biomarkers, including the following relatively well-established ones (USEPA 2006):

- *Delta-aminolevulinic Acid Dehydratase (ALAD).* Elevated concentrations of this enzyme in birds and perhaps amphibians can indicate sublethal exposure, within the previous month, to lead from highway runoff or birdshot.
- *Acetylcholinesterase (AChE).* Depressed concentrations of this enzyme in birds, amphibians, and invertebrates can indicate exposure, generally within a few hours or days, to organophosphorus and carbamate insecticides (Ludke et al. 1975), and perhaps to some heavy metals.
- *Cytochrome P450 Monooxygenase System (MO).* Elevated concentrations of this enzyme in birds can indicate exposure, within the previous few days or weeks, to various organic hydrocarbons.
- *Hexacarboxylic Acid Porphyrin (HCP).* Elevated concentrations of this enzyme in birds can indicate ongoing exposure to various organic hydrocarbons.

  Retinol (Vitamin A). Depressed concentrations of this enzyme can indicate reduced viability of individual birds.

  Thyroid hormones. Depressed concentrations of various thyroid hormones in birds can indicate ongoing exposure to various organic hydrocarbons.

Laboratory costs for analysis of any of the above biomarkers generally range from \$15 to \$75 per sample, processed at a rate of about 20 to 30 samples per day. Other potential biomarkers for use with terrestrial vertebrates are described in Harder and Kirkpatrick (1994).