

Chapter 4. MONITORING AND FOCUSED RESEARCH PROGRAM DESIGN

Part A, INTRODUCTION AND READER'S GUIDE

Thirty CMARP Workteams developed conceptual models and monitoring and research recommendations based on the information needs of the eight CALFED programs (Ecosystem Restoration, Water Quality, Delta Levees System Integrity Storage, Conveyance, Water Transfers, Water Use Efficiency, and Watershed Management Coordination) and supporting programs (Category III and Conservation Strategy). This chapter summarizes the CMARP Workteam monitoring and research recommendations for each CALFED program. Details of the conceptual models and associated monitoring and research plans appear as appendices to this report. Each section (Chapter 4.A-K) addresses the following:

- CALFED mission, goals and objectives— Lists relevant CALFED goals and objectives addressed by the proposed monitoring. In some cases, monitoring for one CALFED program may fulfill goals and objectives of other CALFED programs.
- Goals and objectives of monitoring plan— Explains how the monitoring plan addresses CALFED goals.
- Monitoring elements— Summarizes the major monitoring elements for each common program.
- Research recommendations— Lists the most important research recommendations for each common program.
- Linkages among program elements— Identifies the linkages between monitoring for a particular CALFED program and the monitoring proposed for other CALFED programs. Identification of the linkages is important for integration of monitoring elements into a cohesive and coordinated program.

The CMARP workteams recommended 640 monitoring elements and 490 research topics. These recommendations are compiled in two

large spreadsheets as sub-appendices to the Data Assessment and Reporting Team Appendix (Appendix VII.I) and are available on the CMARP web-page. This list includes existing monitoring programs as well as new monitoring recommendations and has not been prioritized.

To provide a broad overview of the monitoring recommendations from all of the CMARP Workteams, Table 4-1 summarizes the recommended monitoring elements and integrates them with indicators proposed by the CALFED ERP Indicators Group. Some workteams, such as Delta Levees System Integrity, also identified indicators. However, for illustration purposes, only the proposed ERP indicators are included in this table. The monitoring elements in Table 4-1 are organized under eight major headings and thirty-three categories. The eight major headings are:

- Biota
- Energetics and Nutrient Cycling
- Geomorphology
- Habitat
- Human Welfare
- Hydrology
- Land use, Water Use & Resource Management
- Meteorology

The categories range from "Birds" to "Bay-Delta Hydrodynamics" to "Water Transfer Effects."

For example, the first category under the "Biota" heading is "Algae & Plankton." The box to the right contains the specific monitoring elements identified for algae, phytoplankton and zooplankton. The listed CMARP workteams for the Water Quality Program (WQ) and Ecosystem Restoration Program (ERP) recommended various subsets of these monitoring elements. The next box to the right contains related indicators proposed by the CALFED ERP Indicators Group.

Future work will include developing and linking indicators to identified monitoring elements for all programs. Indicator selection and development are discussed briefly in Chapter 5.

Table 4-1. Summary of Monitoring Elements recommended by CMARP Workteams and merged with indicators proposed by the CALFED ERP Indicators Group. The monitoring elements are arranged under the general headings of Biota, Geomorphology, Energetics & Nutrient Cycling, Habitat, Human Welfare, Hydrology, Land use & Resource Management, and Meteorology. Each general heading is further organized into categories. Workteams are organized by CALFED Program (**DL**: Delta Levees System Integrity; **ERP**: Ecosystem Restoration Program; **WMCP**: Watershed Management Coordination Program; **WQ**: Water Quality; **WT**: Water Transfers; **WUE**: Water Use Efficiency). Indicators Group designations are: ARFE=Alluvial River-Floodplain Ecosystem, DE=Delta, SFBE=Greater San Francisco Bay, URFE=Upland River-Floodplain Ecosystem; No designation refers to all systems.

Category	Monitoring Elements	CMARP Workteams	Proposed Indicators (ERP Indicators Group)
BIOTA			
1 Algae & Plankton	Algae: Community survey; biomass relative to nutrients Phytoplankton: Biomass; primary productivity; species composition; assemblages Zooplankton: Presence/absence; abundance; community; species abundance; biomass; size composition; secondary production; flux	WQ: Sacramento River, San Joaquin River, Contaminants ERP: Hydrodynamics, Benthic Macroinvertebrates, Fluvial Geomorphology, Estuarine System Productivity, Shallow Water Habitats, Fish X2, Salmon	Trends in abundance, diversity, composition, and distribution of native phytoplankton and zooplankton assemblages (DE, SFBE); Abundance of zooplankton (DE, SFBE); Primary production rates (DE, SFBE)
2 Birds	Abundance; distribution; reproduction; species richness/diversity; percent breeding species; reproductive success; percent migrants, genetic diversity, guild structure; clutch size; behavior; sign	ERP: Fluvial Geomorphology, Shallow Water Habitats	Trends in abundance, reproductive success, diversity, composition, and distribution of native resident and migratory birds; Population trends of selected listed species
3 Contaminants (Biota)	Algae: Community assessment Birds: Organochlorines, Hg, Se in eggs; Contaminant load Fish: bioaccumulation of metals, trace elements, organics, Hg, PCBs, chlorinated insecticides; condition indices; bioassessment surveys; exposure effects; contaminant load Invertebrate-clams, crustaceans: bioaccumulation of metals, trace elements, organics, condition indices; contaminant load Invertebrates: bioassessment, exposure effects Small mammals: contaminant load Plankton: Phytoplankton & Zooplankton exposure effects Vegetation: contaminant load, bioassessment	ERP: Estuarine System Productivity (lower), Shallow Water Habitat, Fluvial Geomorphology WQ: Contaminants, Sacramento River, San Joaquin River	Toxicity Concentrations in water and sediment Tissue concentrations Bioassays Biomarkers Bioindicators Contaminant loading
4 Fish	General: striped bass, splittail, white & green sturgeon, American shad, salmon, steelhead, resident fishes distribution & abundance; relative abundance; community survey; species richness; condition indices; diet; feeding success; biomass; health; growth rate; size class distribution; reproductive success; lamprey spawning; flux; secondary production; species of special concern; distribution of larvae, juveniles, adults in floodplains; emigration past fish ladder; exports from bypasses to rivers; fish screening effects- number salvaged & lost by species; ocean abundance of salmon prey; harvest of wild & introduced species Delta Smelt: Adult, juvenile, larval, spawning Salmon & Steelhead: -Adult: ocean conditions; migration timing; straying; pre-spawning mortality; harvest (angler survey, creel survey, ocean); survival; escapement (carcass) surveys; age analysis; redd distribution & stranding rates; egg viability; origin determination; percent hatchery fish in escapement; hatchery fish gamete viability; habitat use; steelhead/rainbow trout allelic variation, dietary analysis, distribution -Juvenile: Outmigration abundance, timing, maturity; distribution vs. streambed complexity; growth; lipid storage; abundance & health indices; stranding rates; smoltification timing; smolt survival; fry emigration	ERP: Bay-Delta Productivity (upper), River Resident Fish, Steelhead, Fluvial Geomorphology, Fish X2, Hydrodynamics, Shallow Water Habitats, Delta Smelt, Salmon WQ: Contaminants, San Joaquin River, Sacramento River	Trends in abundance, diversity, composition, distribution and trophic structure of natives resident and anadromous fishes; Presence and distribution of native and migratory fish species; Population trends of selected listed species; Number of unnatural barriers interfering with natural movements of native species, flow, sediment & nutrient transport/supply (DE), Cohort replacement & survival rates of selected life stages of certain fish (DE); Invasive introduced species -- Measures of new invasions; Abundance, spatial extent and distribution of selected species; Number of selected species eradicated or exhibiting no net increase in distribution.

	Category	Monitoring Elements	CMARP Workteams	Proposed Indicators (ERP Indicators Group)
5	Non-Indigenous Species	Non-indigenous species (invasive fish, invertebrates, animals, plants)- Percent non-indigenous species; presence; distribution; trends; transport & release; new introductions; monitor floating docks & buoys, shallow water margins, small water bodies, small tributary rivers and sloughs, artificial or altered lagoons, shipping facilities & ship exteriors, ship ballast water discharges & seawater system, baitworm seaweed & water packing; Update species keys;	ERP: Shallow Water Habitats, Non-Indigenous Species, Fluvial Geomorphology, Resident Fish WMCP: Watershed	Invasive introduced species: -Measures of new invasions -Abundance, spatial extent and distribution of selected species -Number of selected species eradicated or exhibiting no net increase in distribution
6	Invertebrates	Benthic: taxa richness, diversity, EPT taxa & index; dominant species, percent dominant taxon, Hilsenhoff Biotic Index, biomass; size distribution, species composition and abundance; community analysis; secondary production; Terrestrial: abundance, diversity, composition, distribution Aquatic: distribution; abundance; harvested species' diet & health; mysid abundance	ERP: Salmon, Benthic Macroinvertebrates, Fish X2, Estuarine System Productivity, Bay-Delta System Productivity, Shallow Water Habitats WQ: Contaminants, San Joaquin River, Sacramento R.	Trends in the abundance, diversity, composition, and distribution of benthic invertebrate assemblages, by functional group (DE, SFBE); Trends in the abundance, diversity, composition, and distribution of riparian insect assemblages, by functional group (URFE, ARFE); Population trends of selected listed species; Secondary production of zoobenthos (DE, SFBE)
7	Vegetation	Canopy cover; productivity; biomass; plant architecture; distribution, abundance, richness; riparian structure, stand attributes; upland land cover and structure; vegetation changes after flooding	DL: Delta Levees ERP: Fluvial Geomorphology, Shallow Water Habitat WMCP: Watershed	Trends in distribution, diversity, and structural complexity of native plant associations; Population trends of selected listed species
8	Terrestrial & Aquatic Species (General)	Status, distribution, abundance & population trends by taxa in floodplain, riparian, wetland habitats, bypasses & riparian corridors; Extent, distribution, population trends of commercial/recreational species; reproductive success; individual morphometry; harvest of wild & introduced species; wildlife-incidence of disease & deformities; trophic structure; small mammals (biomass, genetic diversity, sign, species richness, trends in diversity, composition & distribution); water conservation & water transfer environmental effects; mitigation for levee improvements;	DL: Delta Levees ERP: Fluvial Geomorphology, Shallow Water Habitats WMCP: Watershed WT: Water Transfers WUE: Water Use Efficiency	Trends in the abundance, diversity, composition, and distribution of native mammals (URFE, ARFE, DE); Fish and wildlife health; Population trends of selected listed species
ENERGETICS & NUTRIENT CYCLING				
9	Energetics & Nutrient Cycling	Primary productivity, carbon pools; nitrogen fixation; detritus composition & transport; organic carbon input in brackish estuaries; flux of organic carbon, N, P in freshwater/tidal marshes; planktonic nutrient cycling; chlorophyll; vegetation biomass, carbon content & litter accumulation; carbon & nutrients following flood events; microbial communities & production. Ratio of floodplain to river production; export of organic materials from floodplain to river channel [See also nutrients in Water Quality, Sediment, & Soils]	ERP: Fish X2, Fluvial Geomorphology, Shallow Water Habitats, Estuarine System Productivity WMCP: Watershed WQ: Sacramento River, San Joaquin River	Nutrients from salmon carcasses(URFE); Organic input from grazing animals (URFE); Nutrient loading (DE); Ratios of natural to anthropogenic sources of nutrients (URFE); Ratio of floodplain to river production (ARFE); Export of organic materials from floodplain to river channel (ARFE); Percent increase in dissolved N and P after overbank flows (ARFE); Dissolved N and P in groundwater at selected sites (ARFE); Flux of detrital organic matter (DE, SFBE);
GEOMORPHOLOGY				
10	Aquifers	Boundary delineation & compaction; regional and local mapping of hydrogeologic boundaries; thickness and degree of confinement	WT: Water Transfers	
11	Channel	Bathymetric surveys; structural complexity; channel & bank stability & erosive resistance; streambed complexity; cross-sectional profile, hydraulic geometry, meander geometry, longitudinal profile, channel density, network order, channel changes after flooding; number freely meandering river miles;	DL: Delta Levees ERP: Hydrodynamics, Salmon, Benthic Macroinvertebrates, Steelhead, Shallow Water Habitats, Fluvial Geomorphology WMCP: Watershed	Mean width of available meander corridor (ARFE); Percent of river length not constrained by constructed levees (ARFE); pool to riffle ratio (URFE); Inter-annual comparison of fluvial geomorphic features (URFE); Percent of river miles exhibiting naturalistic meandering (ARFE); Linear distance of channels per unit area (DE); Proportion of 1st, 2nd, 3 rd order channels/ unit area(DE); Bank slope(DE)

	Category	Monitoring Elements	CMARP Workteams	Proposed Indicators (ERP Indicators Group)
12	Land	Subsidence (Delta island, Delta levees, Central Valley); land surface altitude; topographic/geologic characterization; landslides; floodplain features, surface roughness, basin topography	DL: Delta Levees ERP: Fluvial Geomorphology WT: Water Transfers WMCP: Watershed	Difference in percent of area flooded during MHHW versus MLLW (DE)
13	Sediment	Chemistry: ionized ammonia, total sulfides, total organic carbon, total nitrogen; phosphorous; micronutrients; salinity; pH; redox potential; conductivity Contaminants: Se, organics, organochlorines, resuspension mercury; toxicity; trace elements & metals; Physical: Texture; composition; grain size; particle size distribution; bulk density; deposition & resuspension dynamics; floodplain, bank, & channel deposits; organic matter; depth of detritus; substrate permeability; sediment production background rates; bioturbation depth; [See Water Quality for suspended sediments]	ERP: Estuarine System Productivity, Salmon, Fluvial Geomorphology, Shallow Water Habitats, Hydrodynamics, Benthic Invertebrates WQ: Contaminants WMCP: Watershed	Bedload movement (URFE); Sediment particle size and distribution (URFE, ARFE); Net change in depth per unit time of unconsolidated sediment (URFE, ARFE); Amount of coarse sediment delivered (as a proportion of pre-dam) (ARFE); Lateral exchange: river to floodplain (ARFE); Inter-annual comparison of fluvial geomorphic features (ARFE); Marsh plain & mudflat elevation relative to sea level (DE, SFBE); Change in area of Delta islands and islets (DE); Net sediment accretion rate relative to rate of sea-level rise at subtidal and intertidal sites (SFBE);
14	Soils	General: stability and erosive resistance; horizontal & vertical accretion & erosion; C, P, N, micronutrients, salinity, redox, pH; moisture; organic matter, particle size distribution; contaminants Peat & organic: oxidation; gradation, organic matter content, moisture, void ratio, compressibility, vertical & horizontal extent;	DL: Delta Levees ERP: Fluvial Geomorphology, Shallow Water Habitat WMCP: Watershed Management	
HABITAT				
15	Habitat	General: habitat spatial extent, configuration, distribution, connectivity; patch classification, size frequency, diversity, temporal variability; habitat metrics & quality; tidal wetlands with natural flooding; total shoreline length; floodplain habitat proximity to topographic features, e.g. location of the thalweg & littoral zone; aerial extent of wetlands and seasonally wet environments; riparian habitat delineation & areal extent; detritus & debris; Vegetation: horizontal cover and vertical structure; canopy cover; riparian forest width, height, density relative to water temperature; changes after flooding Channel: river habitat vs. fish assemblage; floodplain inundation, frequency & duration; channel changes after flooding; steelhead & salmon rearing habitat & spawning habitat investigations & restoration; flooding effects on salmonid habitat; Stressors: impacts due to levee improvements & compensatory mitigation; occurrence of unnatural barriers interfering with movements of native species; water transfer & water conservation environmental effects; response to levee breaches/removal	DL: Delta Levees ERP: Steelhead, Fluvial Geomorphology, Salmon, Shallow Water Habitats, Benthic Macroinvertebrates WMCP: Watershed WT: Water Transfers WUE: Water Use Efficiency	Extent and distribution of patches of all natural habitat types; presence and distribution of species requiring multiple habitats; Abundance, distribution, and recruitment rate of large woody debris (URFE); Shaded riverine aquatic habitat (URFE); Diversity of flow velocity (URFE); Distribution and extent of floodplain habitats (ARFE); Distribution and extent of littoral zone (ARFE); Percent of river length not constrained by constructed levees (ARFE); Connectivity of riverine channels to wetlands (DE); ; Length of river channel obstructed by artificial barriers; Length of riparian corridor unobstructed by artificial barriers;
HUMAN WELFARE				
16	Flood	levee inspection, high water monitoring & staking; flood emergency response status; flood fighting support; levee technical assessment	DL: Delta Levees	
17	Health	Risk assessment for Hg, Se; Mitigation of Se inputs into ducks, crabs & fish; drinking water impacts	WQ: Contaminants	Toxicity: Concentrations in water, sediment, tissue, bioassays, Biomarkers, Bioindicators, Contaminant loading;
18	Population/ Demographics	Population; population within water service area boundaries;	WT: Water Transfers WUE: Water Use Efficiency	

	Category	Monitoring Elements	CMARP Workteams	Proposed Indicators (ERP Indicators Group)
19	Socio-Economic	<p>General: Income; rural businesses sales & employment; social & economic values related to community involvement, watershed management, recreation, habitat extent & species diversity; third party effects of water transfers and conservation; recycled water expenses & use benefits; delta operations outages, power operations & costs</p> <p>Agriculture: Value of agricultural output; agricultural employment; labor force and unemployment; social and economic values related to agricultural practices</p>	<p>WMCP: Watershed WT: Water Transfers WUE: Water Use Efficiency</p>	
HYDROLOGY				
20	Bay-Delta Hydro-dynamics	3D-Hydrodynamic Model; X2; delta export rates; channel tidal flows; historical bay-delta hydrodynamics studies; horizontal current patterns; ocean currents; sea level rise; shallow water hydrology; tidal prism conservation; hydroperiod; tidal regime; tidal prism; tidal time series flow; net tidally averaged flow; upwelling; water depth;	<p>DL: Delta Levees ERP: Hydrodynamics, Salmon, Shallow Water Habitats, Estuarine System Productivity WT: Water Transfers</p>	Water movement and vertical mixing at select locations throughout Bay (SFBE); X2 location (SFBE); Salinity at selected locations in the Bay (SFBE);
21	Flow	Adequate streamgage network; Daily flow; depth; diversions & withdrawals; Delta operations flow requirements; Delta inflow & outflow; installation & removal of barriers; flow gate operation; inflow rate; river time series; stage (height); discharge; velocity; velocity profiles; vertical hydraulic gradient; flood frequency & inundation; changes due to setback levees; peak flows; pulsing, flooding regime; floodplain inundation, frequency & duration; characterization of low flows; historic streamflow & stage data; hydroperiod; flow predictions from snowmelt & runoff models- runoff; evaporation; infiltration	<p>DL: Delta Levees ERP: Fluvial Geomorphology, Estuarine System Productivity, Salmon, Hydrodynamics, Shallow Water Habitat, Benthic Macroinvertebrates, Steelhead SC: Storage & Conveyance WMCP: Watershed WQ: Contaminants, San Joaquin River WT: Water Transfers</p>	Minimum base flows (URFE, ARFE); Seasonal shifts in river level (URFE, ARFE); Measures of variability (URFE, ARFE); Geographic distribution of flows (ARFE); Delta outflow (DE); X2 location (SFBE); Salinity at selected locations in the Bay (SFBE); Minimum surface area of floodplain inundated at least once every 2 years and every 10 years (ARFE); Flood duration (mean and variability) (ARFE); Mean annual frequency of floods (ARFE); Composite measures for freshwater flow rates, water residence time, and flow direction for selected channels (DE); Flows of tributaries mimic pattern of unimpaired flow (DE);
22	Groundwater	Discharge & recharge; levels; movement; water quality; sources; wetland storage & streambank storage; net infiltration	<p>DL: Delta Levees ERP: Fluvial Geomorphology WMCP: Watershed WT: Water Transfers</p>	Depth of water table (ARFE); Soil moisture levels, laterally from banks (ARFE); Characteristic plant communities (ARFE); Width of riparian corridor (ARFE)
23	Reservoirs	Conditions; water quality; temperature; storage; suspended sediments deliver & types to impoundments	<p>ERP: Steelhead WMCP: Watershed WT: Water Transfers</p>	
24	Water Quality	<p>Contaminants: Pesticides & other organic chemicals, MTBE, bromide, dissolved & total organic carbon, THMFP, dissolved & total trace metals including mercury & methylmercury, selenium, pathogens, nutrients. Contaminants & nutrient loading from sources such as dredging operations, wastewater discharge, cannery effluent, urban runoff, dairies, farms & rangeland. Aquatic toxicity to invertebrates, algae, fish.</p> <p>Chemistry: Alkalinity; pH; conductivity; dissolved oxygen; hardness; major ions; C, P, N, micronutrients; nutrients-organics; BOD; salinity; TDS; total organic carbon; strontium in steelhead spawning streams; chlorophyll</p> <p>Physical: Light attenuation; irradiance; total suspended solids; turbidity; temperature; suspended sediment flux, bedload, solute load</p>	<p>DL: Delta Levees ERP: Fluvial Geomorphology, Benthic Macroinvertebrates, Fish X2, Salmon, River Resident Fish, Estuarine System Productivity, Steelhead Hydrodynamics; Shallow Water Habitat WMCP: Watershed WQ: Contaminants, Sacramento River, San Joaquin River, Drinking Water WT: Water Transfers</p>	Toxicity: Concentrations in water and sediment, Tissue concentrations, Bioassays, Biomarkers, Bioindicators, Contaminant loading; Salinity at selected locations throughout the Delta (DE); Dissolved oxygen; Turbidity-suspended solids; Nutrients (N, P, C); Salinity/TDS

Category	Monitoring Elements	CMARP Workteams	Proposed Indicators (ERP Indicators Group)
LAND USE, WATER USE & RESOURCE MANAGEMENT			
25	Land use	General: Land use, trend analysis, history, intensity, management practices; presence & type of human activities near streams, riparian areas & habitats; logging; mining; point sources of sediments & contaminants; urbanization; roads & road-building; wildfire & fire suppression; watershed improvement practices; program personnel turn over & funding; shoreline development; Agriculture: Number & size of farms; crop patterns; land use surveys including irrigation method by crop; grazing; management practices; chemical applications; pesticide management effectiveness;	ERP: Fluvial Geomorphology, Shallow Water Habitats WMCP: Watershed WQ: Contaminants WT: Water Transfers WUE: Water use efficiency
26	Levees & Impoundments	Levee: Levee cross-sections, profiles & maintenance quality inspections; levee miles or islands/tracks meeting minimum PL84-99 standard, with enhanced flooding protection, with seismic upgrades, with subsidence control measures; assessment of set-back levee restoration efforts; [see also Geomorphology] Impoundments:	DL: Delta levees ERP: Fluvial Geomorphology WMCP: Watershed
27	Water Deliveries & Transfers	Surface water; recycled water; history of water transfers; water transfers among agencies within the projects	WMCP: Watershed WT: Water Transfers WUE: Water Use Efficiency
28	Water Recycling	Amount produced/used in supplier service area, quality of source water & recycled water; wastewater collected/treated; wastewater discharge; water quality effects on recycled water production & usage	WUE: Water Use Efficiency
29	Water Use	Agriculture: EWMP implementation; land use/acreage by irrigation methods; irrigation amounts & efficiency; real time Eto; crop coefficients; length of canals & laterals; canal seepage; reduction in applied water & groundwater depletion; surface & subsurface drainage water & ground water reuse; delta water use surveys; Environmental: Operational commitments to fisheries; wetland restoration evapotranspiration rates Urban: Applied water reduction; BMPs; commercial, industrial, & institutional customer data; landscape irrigation efficiency; groundwater depletion; interior water use; irrigated landscape acreage surveys; water management plans; water use per capita data by customer class, water district, hydrologic region; water use efficiency estimates; seasonal & peak water use; water audits & leak detection	WMCP: Watershed WUE: Water use efficiency
METEOROLOGY			
30	Air	Mercury deposition; organochlorine source loading; relative humidity; temperature; wind speed & direction	ERP: Estuarine System Productivity WQ: Contaminants
31	Precipitation	Amount, timing & form; snow-pack & snow-melt dynamics, sunlight, weather, weathering	ERP: Estuarine System Productivity WMCP: Watershed