California Rivers Assessment:

Assembling Environmental Data to Characterize California's Watersheds

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Abstract

The California Rivers Assessment (CARA) is a computer-based geographic data management system designed to give resource managers, policy-makers, landowners, scientists and interested citizens rapid access to essential information and tools with which to make sound decisions about the conservation and use of California's rivers. CARA is intended to provide an evaluation of the environmental conditions of California's rivers by integrating existing data from previously uncoordinated contributors and organizations, and to improve river conservation and management by making this information available and useful. The assessment utilizes a suite of watershed facts, processed in ESRI's ARC/INFO and ArcView Geographic Information System software, to provide an objective view of the watershed integrity of California's riverine resources. These watershed facts focus on existing riparian and aquatic resources: biodiversity, water quality, and resource management activities. Access to this multi-leveled, interconnected database of California watershed environmental data is provided and enhanced by innovative World-Wide-Web technology.

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Background

The California Rivers Assessment (CARA) is an interagency program co-sponsored by 28 federal, state, and private resource agencies and conservation programs. Its goal is to map and assess the status of selected riparian and instream resources to assist in setting priorities for water allocations, riparian restoration efforts, and other aspects of environmental policy. Development of the project began in the summer of 1992. An executive council was formed in early 1993, and technical committees met later in the spring. The project began in December 1993, with the California Resources Agency, several programs within EPA, and the National Park Service all providing substantial support (approximately $900,000 to date). Many more programs have provided data, staff resources, and technical assistance.

CARA provides an evaluation of the environmental conditions of California's rivers using the best existing data from many contributing researchers and organizations. The goal of CARA is to improve river conservation and management by integrating this information through the development of shared spatial descriptors and resource categorizations. The initial focus on riparian and aquatic components reflects both the central value of the biological components of rivers and streams in California's economy and quality of life and the need for much better information by the managers of those resources.

The following description details CARA's mission to develop a consistent set of indicators of ecological conditions that will be used to evaluate riverine resources across the state. These indicators form the basis of an aggregated information model; a detailed, multi-leveled, interconnected database of available river resource information. This model is currently developed by connecting or merging existing electronic databases into the CARA database. Several existing products of the CARA database include CARA Online Query System (1), the California Riparian Evaluation System (CARES) (2), and the Interactive California Environmental Management and Planning System (ICE MAPS) (3). These models represent CARA's mission to provide publicly accessible data, assembled in standardized formats, to depict current environmental information at statewide and watershed scales.

Furthermore, these spatial analyses are currently used by a number of broad constituencies, including state and federal land managers, watershed groups and other public private partnerships, schools, and researchers. Current on-line access is some 6000 hits per week; therefore, consistency and accuracy across watersheds is critical in establishing a framework for common understanding and decision making. The CARA database is unique in its ability to incorporate localized data to more accurately depict watershed information, while still maintaining its broad scale applicability. Thus, the aggregated information model, as presented by CARA, is an Internet-based solution to provide watershed data on a statewide, regional, and local basis. This solution is accomplished by features which allow users to query for data by river, watershed, county, assembly district and other standard geo-locators; to map elements of the CARA database through ICEMAPS; and to identify and provide access to localized information of importance to watershed stakeholders.

Objective

The primary CARA objective is to provide a robust and integrated World-Wide-Web accessible database of environmental facts, to characterize the ecological status of the 149 major watersheds in the State of California.

The traditional approach of protecting biological resources through the establishment of parks and preserves is only partly applicable to rivers. Human activity within watersheds can often have highly detrimental effects even to legally protected stretches through diversion and modifications of natural flows, increased sedimentation, nutrients, and toxic materials in runoff from forest practices, agriculture or human habitations, dams and modification of channel, and other physical and chemical transformations (4). Full protection of these resources requires comprehensive management at the watershed scale after "identifying and evaluating fundamental, system-level components of ecologically healthy watersheds." (5). Preservation of aquatic systems is a multifaceted endeavor, centering on interactions among many contributing processes operating on multiple spatial and temporal scales (5). Several factors have been identified which contribute to determining the status of aquatic resources and watershed health. Natural diversity, both in habitat types and complements of species is perhaps the most important (4). Connectivity in habitat diversity is exemplified by life history patterns in anadromous fishes, temperature regulation of emergent aquatic insects, and nutrient exchange in riparian – lotic systems (5). Ecologically healthy watersheds, as defined by Karr (6), refer to those watersheds that maintain functions critical to biodiversity, productivity, and evolutionary processes. Tangible watershed functions, in addition to habitat and species diversity, are water quality and impacts by human alterations and resource management (5). An additional representation of critical watershed function is through hierarchical analyses; these functions can be depicted through pattern formation and analyzed at differing watershed and landscape scales to more fully realize their importance (7). The use of watershed units, with common ecological descriptors, allows for the comparative analysis of ecosystem properties (7).

These watershed descriptors assembled by CARA focus on existing riparian and aquatic resources: biodiversity, water quality, and resource management activities. The biodiversity components of the on-line portions of the CARA database include the number and locations of naturally occurring waterways; the percentage of free flowing river miles; the percentage of river miles in protected lands; the percent of the watershed area under protected management; the number of rare and endangered species; the number of natural habitats (Holland vegetation types). Water quality parameters include the number of river segments with complete professional judgement assessments; the average precipitation per year within the watershed; the percentage of area above 15% slope; and a water quality index score. Resource management activities currently depicted on-line are the number of dams, the number of stream crossings, and the total length of near-stream roads.

Methods

To accomplish this objective, CARA has compiled a number of different environmental data from various sources, analyzed these data within a GIS, and published the resultant findings through an interactive WWW site dynamically generated from the CARA database. The CARA relational database was assembled and compiled within Microsoft Visual FoxPro 5.0 and is served over the WWW using Microsoft Active Server Pages technology, JavaScript, and ESRI’s MapObjects Internet Map Server within its Hyper Text Markup Language (HTML). The WWW server technology is Microsoft Internet Information Server software on a Micron P6 200Mhz server. All assembled watershed facts were analyzed and processed in either ESRI’s ARC/INFO 7.1.1 for Unix, ESRI’s ARC/INFO Version 7.1.2 for WindowsNT, or ESRI’s ArcView 3.0a. All spatial data coverages were projected into a common format: Albers Conic Equal-Area, the standard projection used by the Teale Data Center and the majority of government GIS centers in California.

Habitat Diversity

Increasingly, planners, regulators, and politicians are shifting environmental management from heavy-handed central regulation to cooperative solutions developed by multiple stakeholders in naturally connected environmental units. Particularly for water-related resources, these units are most naturally watersheds. Watersheds may be defined on a number of different scales, ranging from the drainage of a headwater tributary (typified in California by "Calwater planning units" typically of about 10,000 acres), through major river basins (USGS cataloguing units or state hydrological units), through entire bioregions (the north coast, the Mojave desert). A challenge to CARA has been to catalog activities and resources at the watershed scales most appropriate to information users.

The primary coverage used to depict CARA is the 8-digit Hydrologic Unit watersheds developed by the United States Geological Survey (USGS). These polygons represent roughly an area between one-half and one million acres, and correspond to the drainage of a coastal or main tributary river (e.g., the Big-Navarro-Garcia with 801330.47 acres or the Upper Cosumnes with 421656.38 acres.) Larger watersheds (e.g., the Sacramento River) are somewhat arbitrarily subdivided into polygons of comparable size. CARA watersheds were created by using ARC/INFO ‘clip’ function with the State of California outline on the USGS hydrologic units. There are 149 CARA watersheds, including the rather arbitrary designation of the California Channel Islands into two such watersheds. All subsequent analyses in the CARA database utilize these watersheds to assemble and aggregate the resultant environmental facts.

For example, the unique feature of the aggregated information model, facilitated by the relational database structure of CARA, is the complete cross-boundary transformation of watershed entities to watershed designations at other scales, and to political entities. For example, spatial intersections were performed between CARA watersheds and counties, assembly districts, and congressional districts to create the relational tables used in CARA. This transformation allows for decision makers and their constituents to gather environmental information at the ecologically appropriate unit of watersheds and relate this information back to the spatial boundaries of the cultural institutions in which they participate.

Central to spatially connecting data from dozens of agencies, researchers, and land managers, is shared terminology for geo-location. Geo-locators used by important sources ranged from river names and river mile markers to township-range-section designations and geo-political spatial boundaries. Since aquatic conditions are propagated through the river network and riparian elements are closely connected to stream channels, for the most critical assessments, it is essential to tie the resources to particular river reaches or other analytically useful watershed boundaries. As a result, all environmental and management elements in CARA have been tied to the evolving EPA River Reach File system or to watershed units that depict the relationship of upland features to river reaches. To date, the US EPA River Reach File System is the only statewide data layer to provide both linear features and standardized names for rivers and major streams.

The River Reach File System and related coverages were a primary tool in creating the analysis of water quality and watershed health. Currently, the California Hydrography Database (CHD), a conflation of the US EPA River Reach File 3-alpha relational database and USGS 1:100,000 Digital Line Graphs, includes a wide variety of hydrographic features. The CHD layer originally came from the USGS in digital line graph (DLG-3) data format. DLG-3 data were captured from 1:100,000-scale maps by manual digitizing and raster scanning. There are approximately 3200 DLG files represented in the statewide hydrography data layer. The hydrography layer consists of all flowing waters, standing waters, and wetlands, both natural and manmade which were depicted in the source maps. The Naturally Occurring Waterways (NOW) layer was created by selecting streams and washes from the EPA River Reach File 3-alpha. An ARC/IFO AML was created to select records based on the major and minor code attributes within the CHD. Therefore, the selection process is dependent on the accurate coding of the reach file segments. Records that contained streams (minor code 412), braided streams (minor code 413), washes (minor code 420), intermittent streams (minor code 610), the right bank of a stream (minor code 605), or the left bank of a stream (minor code 606) were retained. The many records with aqueducts, ditches or canals, penstocks, dams, pumping stations, and other artificial structures were eliminated, as well as lakes, ponds and reservoirs. However, a few records of manmade shoreline (minor code 201), which were also coded as left or right bank, were included to maintain the integrity of a river (e.g., rip-rapped banks of rivers). Next, streams with both left and right banks, as opposed to a single arc centerline, were visually identified and flagged in the database as 'double'. This was accomplished by relating the arc level representation to published USGS 1:100,000 topographical quadrangle maps by visual and attribute identification. Lastly, waterways that occurred within lakes were removed; these arcs were generally a centerline from a stream that was subsequently submerged by a reservoir. To analyze the aggregated length of river miles within a CARA watershed, the sum of the lengths of the arcs not flagged as double was added to half the sum of the lengths of the arcs flagged as double. This length of naturally occurring waterways was then analyzed to determine the percentage of free-flowing river. This proportion was determined by ‘intersecting’ the CHD in its entirety with CARA watersheds using and summing the total length of arcs within each. These values were used to divide the total length values determined from the NOW coverage and multiplied by one hundred.

Other watershed measures that contribute to habitat and species diversity are the number of special status species in each CARA watershed. To determine the number for each CARA watershed, the Natural Diversity Database (NDDB) was used. The NDDB contains over 22,800 records for nearly 1,200 native species and natural communities. The NDDB provides information on rare species and natural community locations, condition, dates of observation, precision of sighting, and comments regarding habitat associations, threats, population sizes, as well as state and federal legal status. A valuable tool for conservation, the NDDB provides government agencies and the private sector with information so that informed land-use decisions and resource management can occur. Developers, county and city planners, state and federal agencies, and conservation groups use the NDDB information to determine where declining species and natural communities are located and if planned projects will affect them. The information also is used to identify biologically rich areas that can be targeted for protection through land conservation actions.

Using ARC/INFO, the following functions were used to identify special status species in each CARA watershed. NDDB was 'unioned' with CARA watersheds with the join option. Because NDDB is a regions coverage, a new subclass indicating the appropriate CARA watershed was created with the 'regionquery' function. Given the rapid rate of landscape development in California, records that indicated "extirpated" or "possibly extirpated" were eliminated as probably not reflecting current conditions. Similarly, records older than twenty years were eliminated. Lastly, records that represent aquatic and land communities were removed and used in a different analysis. Thus, a resultant frequency of NDDB occurrences was identified for each CARA watershed. Another facet of habitat and species diversity assembled in the CARA database is the number of habitat types, represented as Holland communities, in each watershed (see Sawyer and Keeler-Wolf for a review of habitat classifications). Holland communities were derived from the Gap Analysis Project (GAP) vegetation layer (GapVeg). This layer contains vegetation attributes for landscape scale map units, including dominant plant species distribution, canopy cover, vegetation classification to Holland Natural Communities types, vegetation series, riparian and wetland types, disturbance, and special interest species distribution. This layer was developed to determine the distribution and current management status of the state's vegetation and habitats. The 'intersect' function was used on GapVeg in ARC/INFO with CARA watersheds. A frequency and listing of Holland types was established to determine the number of unique communities for each CARA watershed. An additional descriptor was the percent of the watershed area currently identified as being managed for biodiversity, as determined by the ARC/INFO 'intersection' of the GAP managed areas layer with CARA watersheds.

Water Quality Measures

Water quality is a fundamental component of watershed integrity because it is a manifestation of geomorphic, hydrologic, and biologic systems and their modifications. Changes in water quality reflect the interconnectedness and complexity of watershed processes (5). Water quality attributes collected in CARA are currently being used for evaluating conditions of water supplies for agriculture and urban uses, for modeling the effects of flow and contaminants on fish populations, to evaluate compliance with the Clean Water Act and other environmental legislation and to report the results to Congress and the public, and as part of an assessment of potential health risks to drinking water supplies.

CARA, in partnership with US Environmental Protection Agency (US EPA) Region IX and the California State Water Resources Control Board (SWRCB), developed a protocol for locating Clean Water Act 305(b) designated waterbodies, as determined through their identification in the Waterbody System (WBS). The WBS is a FoxPro 2.6 DOS database, developed by the Research Triangle Institute, used to represent the water quality assessment of the Nation's waterbodies. Spatial representation in the California Hydrographic Dataset (CHD) was accomplished by associating primary data attributes from each database (Waterbody Identifier – [WBID] to Primary Name Code – [PNMCD]) by a series of decision rules. The first approximation of waterbody location was determined by the [WBLOCN] value of the waterbody in the WBS, whose value indicates a Hydrologic Sub Area watershed, as identified by SWRCB. This process minimized commission errors, in which several waterbodies with the same common name may be mistakenly coded. Waterbodies were then identified in the CHD by the [PNAME] attribute, their spatially corresponding named feature on a USGS 1:100,0000 topographical map, and the desired waterbody name [WBNAME]. This cross-walking procedure resulted in a ~95% correspondence for riverine records in the WBS to the CHD, 1253 records out of 1297 for the 1994 data. The 1996 dataset was not as complete due to an increase in the number of records reported in the WBS. Nevertheless, we were successful in relating 1748 of 1836 records, again a ~ 95% success rate. This crosswalking procedure also results in omission errors, in which several records in the WBS can only be identified with a single [PNMCD] in the CHD. This occurs in large riverine waterbodies where upper and lower reaches may be subdivided in the WBS without corresponding subdivision in the CHD.

For the CARA database, the spatially referenced riverine waterbodies were identified and isolated within the NOW representation of the CHD and intersected with the CARA layer. The length for each identified riverine waterbody was calculated for within each CARA watershed to establish relative contribution to watershed processes. The WBS water quality assessment values were then used to calculate a relative water quality indicator. These values represent estimates of the degree to which parts of each river system support beneficial uses (fisheries, water supply, recreation, etc.) defined by regional water boards in the basin plan for each watershed. The analysis then evaluates causes of impairment of those beneficial uses, sources of any impairment, and Total Maximum Daily Load (TMDL) designation. Calculated scores for these reported assessment values were based on a zero to one scale, one being best. For each reported beneficial use, a score was given based on its level of support: fully supporting received a 1.0, threatened, but supporting received a 0.75, partially supporting received a 0.50, not supporting received a 0.25, and not attainable received a 0.0. These scores were then averaged to determine a relative score for support of beneficial uses. For causes and sources of impairment, each record was given a score based on the magnitude of impairment; no recorded impairments received a score of 1.0, a suspected magnitude received a 0.75, a slight magnitude received a 0.50 score, moderate magnitude received a 0.25 score, and a high magnitude received a score of 0.0. Again, these scores were averaged. Lastly, TMDL designation was scored solely on the waterbody status of designated score of 0.0 or not designated 1.0, regardless of the number of pollutants contributing to its designation. The suite of scores for each waterbody was averaged by the four described parameters to establish an overall index of water quality. These water quality scores were then multiplied by the weighting factor of the contributing waterbody length to each CARA watershed, as described previously, and divided by the total summed length of waterbodies within the watershed to establish a single weighted average water quality index score for each CARA watershed.

$$\text{CARA WQI} = \Sigma \frac{(\text{Waterbody Values } (\bar{u} + \bar{c} + \bar{s} + t) / 4) * \text{Waterbody length}}{\text{Total length of waterbodies in CARA watershed}}$$

Limitations of this method of interpreting water quality through the data in the WBS include the fact that some watersheds do not have a contributing waterbody defined and some watersheds contain only a single waterbody while others have a rich network of waterbodies identified. This lack of spatial designation leads to a disparity in the basis for judgments across watersheds. Another problem is that the WBS water quality assessment is necessarily a coarse scale assessment where some existing waterbody designations are coarser than CARA watersheds (e.g., the Sacramento River is in over ten different CARA watersheds). Finally, many waterbodies within the WBS have values of ‘not assessed’ for beneficial uses; these records were eliminated from the CARA scoring process. However, the WBS and its results will be more spatially robust in the future as US EPA and the SWRCB work with CARA to more accurately depict the spatial extent of waterbodies in GeoWBS, an ArcView user interface that helps bind waterbodies to primary spatial coverages in a GIS (8).

Additionally, the CARA database contains the number of river segments with complete Professional Judgement Assessments (PJAs) performed by experts in CARA’s sponsoring agencies. These assessments addressed the status of dozens of resource, use, and management categories along rivers managed by the participating professionals’ agencies. To obtain this information, the CARA advisory committees and staff designed and distributed a questionnaire to more than 1000 individuals in 375 public agencies and private organizations. The PJA questionnaire sought information for 893 river segments in seven categories: riparian habitat conditions, aquatic habitat conditions, special status plants and animals, hydrologic and physical conditions, factors affecting biological integrity, protection and management status and overall biological integrity. Respondents returned information in one or more of these categories for 575 of the 893 segments, as well as information for 41 additional segments that were not part of the original scope. In all, the PJA collected information for 616 segments on 145 rivers. Each piece of information received was geographically coded using both the CARA watershed designation and the River Reach File 3-alpha attributes. This coded data was then entered into CARA's PJA database.

Slope incidence is a primary factor in determining the stability of watershed slopes. This factor largely controls the degree of risk in erosion potential. Slope gradients for the

CARA database were generated by using the 'slope' function in ARC/INFO GRID on a 3-arc-second Digital Elevation Model of the State of California. These percent slope cell values were used classify the risk of erosion potential through bank instability as a function of the area of the CARA watershed. This parameter, erosion potential, is heavily influenced by the amount of annual precipitation. To determine the average rainfall within each CARA watershed, a coverage of precipitation isohyets was used in ARC/INFO with the 'intersect' function with CARA watersheds to create a watershed based representation of precipitation.

The precipitation coverage represents lines of equal rainfall, isohyets, based on long-term mean annual precipitation data compiled from USGS, California Department of Water Resources, and California Division of Mines map and information sources. Source maps are based primarily on U.S. Weather Service data for approximately 800 precipitation stations throughout California collected over a sixty-year period (1900-1960). The minimum mapping unit is 1000+ acres and the isohyetal contour intervals are variable due to the degree of variation of annual precipitation with horizontal distance. The CARA database utilizes a weighted average to determine a single value of mean annual precipitation; the isohyetal areas, after intersection, are multiplied by the average rainfall for each isohyet-derived polygon and divided by the total area of the CARA watershed.

Resource Management Activities

The integrity of riparian areas is perhaps the best indicator of watershed health (5). Roads are a source of disturbance to wildlife, a source of non-point source pollution, and break the continuity of riparian habitat. Management activities within watersheds beyond road construction include the damming and channelization of rivers. Dams are a significant change in watershed hydrologic processes and also significantly reduce the amount and continuity of riparian habitat. To aid in identifying human activities potentially harmful to watershed processes, several spatial datasets were analyzed and assembled in CARA, including the proximity of roads to streams, the number of roads that cross over streams, and the number of dams in each watershed.

A riparian zone coverage was created by using the 'buffer' function in ARC/INFO on the NOW layer at a one hundred meter distance. The total length of streamside roads within a CARA watershed were determined by summing the total length of arcs derived by using the ARC/INFO 'intersect' function with the riparian zone coverage and a statewide roads coverage. The roads layer is based on the USGS DLG transportation linework derived from the DLG-3 digital series. The roads layer contains several classes of transportation features including jeep trails, city streets, thoroughfares, unpaved roads, state highways, and interstates. This layer is only as complete as the USGS 1:100,000 quadrangle maps used to create it, some of which date back to the 1970s. Recent areas of urban growth are not as complete. On the other hand, the information the layer includes jeep trails and some logging roads not shown on most coarse scale maps. Additionally, not all classifications occur in each county, and classification of secondary roads can be somewhat inconsistent between 1:100,000 quadrangles.

The number of dams in a watershed was calculated by using the 'intersect' function in ARC/INFO on jurisdictional dams with CARA watersheds. Jurisdictional dams are represented by a point coverage of "Dams within the jurisdiction of the State of California" (9). Jurisdictional Dams are defined as "artificial barriers, together with appurtenant works, which are 25 feet or more in height or have an impounding capacity of 50 acre-feet or more. Any artificial barrier not in excess of 6 feet in height, regardless of storage capacity, or that has a storage capacity not in excess of 15 acre-feet, regardless of height, is not considered jurisdictional." (9). The current coverage includes some 1427 dams. CARA has developed ArcView tools, not currently available over the Internet, to assist public officials in assessing the potential for riparian habitat restoration and land acquisition, using environmental bond funds and other public monies. The occurrence of natural drought-flood cycles (which only occur upstream from major dams), is an essential part of that analysis (2).

Future Directions and Conclusions

The CARA database, as analyzed through the number of logged events on the WWW server, indicates a high usage by a broad user constituency. CARA currently generates an average of 6,946 hits per day. The user base is broad, with the largest usage coming from subscribers to commercial Internet service providers and Internet search engines. This user segment largely represents public participants interested in watershed information. The other two most frequent users groups represent academic and professional use of the system. The on-campus student / faculty population at UC Davis generate about 4 % of the users as do the governmental domains of the State of California (data was compiled by Microsoft Usage Analyst for all the WWW based files administered by CARA). Substantial use, as estimated from both domain names and e-mail traffic, is from K-12 schools. The largest user groups represented in correspondence are local managers, including agency field offices, city and county officials, and private watershed councils, friends of the river groups, and regional environmental organizations.

The broad level of general public interest in CARA and watershed information is the primary driving force creating priorities for the future direction of CARA activities. Namely, the inclusion of localized datasets at the watershed level. Contemporary law and policy that governs land use and natural resource planning in California establishes significant authority at the local level. The establishment of regional and statewide goals for natural resource management implies a need for local participation and must assume a high degree of citizen participation in the planning process. Three longstanding problems have hampered the effectiveness of this framework. The first is the lack of a ready source of publicly available natural resource information at the local level. The second is the failure to connect discrete local actions into a regional analysis of impacts and opportunities. The third is the lack of an information integrating system that would allow for local and regional studies to be incorporated into a statewide framework.

Future CARA activities include addressing these problems through the creation of a model system of integrated inter-organizational training, data collection, data management, and data communication. The resources of CARA, watershed groups, and county planning agencies will be used to demonstrate the feasibility and decision making impact of involving citizen-activists and elected and appointed local officials in the process of creating and interpreting information of local, regional and statewide significance.

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