

Mapping Urbanized and Rural Drainages in the Bay Area:

A Tool for Improved Management of Stormwater Contaminants Derived from Small Tributaries

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Executive Summary

San Francisco Bay is listed for a number of trace substances on the Clean Water Act 303(d) list of impaired water bodies. Trace substances enter the Bay via a variety of pathways including point source discharges, diffuse sources from local small tributaries and urban drainage, the Central Valley drainage via the Delta, atmospheric deposition, and dredge material redistribution. Recent reviews have suggested that for some trace substances, local small tributaries and urban drainages may provide a significant load. It follows that mapping, characterization of sources of substances of concern, and prioritization of local tributaries and urban drainages for research and management will be necessary to improve water quality in the Bay. It was recognized by the Sources Pathways and Loading Workgroup of the Regional Monitoring Program for Trace Substances that a first step was to analyze existing digital storm drain map data in the Bay Area. This report outlines the results of that effort and makes recommendations for the future improvement of digital mapping in Bay Area local tributaries. The greatest successes of the project were 1. The completion of the National Hydrography Data Set (NHD) for the Coyote Creek Catalogue Unit, 2. An evaluation of the quality of existing digital storm drain maps, 3. An evaluation of how to compile storm drain maps in the context of evaluation of sources, pathways, and loadings of trace substances, and 4. A pilot development of watershed boundaries for Bay Area watersheds.

Cities and counties in the Bay Area are presently utilizing a range of software alternatives for building and displaying digital storm drain information including CAD (e.g. AutoCAD and Microstation), GIS (ArcView 3.2, Arc 8.0, Arc 8.1, GeoMedia, and MapInfo), and relational databases such as Oracle and Informix. Cities and counties collect digital storm drain information for a variety of reasons (e.g., the development and maintenance of the networks, resource inventory, new development or redevelopment approval, tracking illicit discharges, and monitoring and modeling the quantity and quality of urban runoff). Setting aside the differences in software platform, the existing data in the Bay Area vary in quality from: 1. GPS field verified, 2. Digitized, verification ongoing, 3. Digitized, verification in near future, 4. No verification, 5. Near real location schematic with ongoing update using as-built drawings and field verification at the non-GPS level, and 6. Schematic only. In addition, metadata are not always available because they were never recorded digitally or because of staff turnover and loss of accumulated knowledge. Many cities and all county flood control districts have developed maps of watershed and sub-watershed boundaries. These are usually developed using 2 or 5 feet topographic contours derived from aerial photography and storm drain information where it exists. In summary, at present, there are not sufficient storm drain coverages yet developed with suitable quality and metadata to complete a regional map for the purpose of accurately defining natural and modified hydrography. This implies that if a regional analysis is to be done on the flow of water and contaminants from urban watersheds surfaces, an alternative method that integrates storm drain coverages (where they exist) with topographic information and existing watershed boundaries delineated by county flood control districts remains the best solution.

The 24K NHD Catalogue Unit (CU) for Coyote has been completed in ArcInfo coverage format. The CU can be obtained by contacting SFEI, is displayed on SFEI's EcoAtlas On-line (www.ecoatlas.org), and can be queried using reach codes. The San Francisco Bay and San Francisco Coastal Southern CU will be completed by the end of

June 2002. SFEI is currently undertaking an effort to develop funding for the three remain Bay Area CUs (Tomales-Drakes Bays, San Pablo Bay, and Suisun Bay CUs).

A pilot synthesis of NHD and storm drain coverages was created and includes all of the Bay Area. Watersheds were generated down to the upper limits of the Baylands margin. Data sources included the Coyote and San Francisco Bay 24K NHD CUs, manually attributed USGS 24K blue lines for the other CUs, Oakland Museum/ William Lettis & Associate's urban watershed delineations for the East Bay, higher resolution watershed delineations for Alameda County, and high-resolution boundaries from SFEI's detailed watershed assessment efforts. The draft layer can be obtained by contacting SFEI or can be viewed and queried on SFEI's EcoAtlas On-line demonstration (www.ecoatlas.org).

At the request of local managers, a "how to manual" was created that includes steps on determine if the layer is contiguous, and steps on dealing with flow direction, disjunct features, and feature attribution.

Given the current status of storm drain mapping in the Bay Area, the range of software platforms, data accuracy, and meta data standards, the lack of an agreed upon methodology to improve mapping, the massive cost associated with storm drain mapping, and the variation in time frames over which local entities will make improvements, SFEI makes the following recommendations on how to fill data gaps and maintain and update a regional spatial dataset and associated attribute files.

- 1. Institutional support needs to be enhanced and funds need to be found to assist Oakland Museum and William Lettis & Associates to continue their effort to compile and field truth drainage systems (including 24 in storm drains) around the margins of the Bay.*
- 2. Institutional support needs to be enhanced and funds need to be found to continue the creation and integration of a regional storm drain layer. This would necessarily include a review of all existing literature regarding storm drain mapping, and storm drain and stream network integration, coordination with the USEPA, USGS and ESRI, the development of a RF3/ NHD storm drain integration methodology, implementation of any necessary changes to RF3/ NHD, a RF3/ NHD storm drain integration pilot in one Catalogue Unit, and RF3/ NHD storm drain integration efforts for the other five Bay Area Catalogue Units.*
- 3. Institutional support needs to be enhanced and funds need to be found to continue storm drain layer maintenance. This would include the development of tools to assist in the integration of storm drain layers with RF3/ NHD, the development of storm drain applications for specific user groups, and the institutional incentives for contributing to the maintenance of a regional storm drain layer.*
- 4. Support the development of watershed boundaries in urban and natural watershed in the context of the need to determine sources and pathways and estimation of loads of contaminants to the Bay. The main obstacles hampering further development of SFEI's product are institutional support, data sharing agreements, and funding. In addition, funding is needed for ongoing maintenance, metadata development, and distribution.*

Acknowledgements

This effort was supported through a grant from the State Water Resources Control Board and managed by the San Francisco Regional Water Quality Control Board. The Sources, Pathways and Loading Workgroup of the San Francisco Bay Regional Monitoring Program for Trace Substances provided oversight and review of the final document. The following groups are acknowledged for the supply of GIS data: City of Fremont, Janet Sowers, William Lettis & Associates, USGS - Sacramento, Christopher Richard - Oakland Museum, City of Oakland, and Paul Modrell - Alameda Countywide Clean Water Program. A number of individuals also provided technical review including:

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Introduction

San Francisco Bay is presently listed (Clean Water Act Section 303(d)) as impaired for mercury, selenium, PCBs, and chlorinated pesticides. There are also concerns about copper, nickel, and PAHs, and potential for future problems associated with the increasing use of pyrethroid-based pesticides and emerging contaminants. In order to develop management strategies for reducing these contaminants, as well as monitoring strategies for measuring the success of management techniques, the Sources Pathways and Loading Workgroup (SPLWG) of the San Francisco Bay Regional Monitoring Program for Trace Substances (RMP) recommended the development of a better understanding of relative inputs from urban point and non-point sources, erosion and resuspension in the Bay, atmospheric sources, and inputs from the Central Valley (Davis et al., 1999).

The issue of coastal contamination is being addressed at management scales ranging from state government down to local governments, special districts, and localized creek groups. To this end, in 1999, the California Legislature, through Assembly Bill 1429, mandated that action be taken to address gaps in knowledge of contaminant discharge to California's coastal waters. San Francisco Estuary Institute (SFEI), the Southern California Coastal Water Research Project (SCCWRP), and the California State University Moss Landing Marine Laboratories (MLML) were directed by the legislation to collaborate and produce a report for the State Water Resources Control Board (SWRCB) detailing current information for the whole California Coast on total discharge of contaminants, identification of the relative contribution of storm water, and recommendations for improvements through monitoring, establishment of standard protocols, standard reporting formats, and estimates of future monitoring program costs.

As part of this mandate, the San Francisco Bay report prepared by SFEI contains estimates of mass emissions to the Bay from the nine county areas immediately adjacent to SF Bay (Davis et al 2000). Where there were sufficient reliable data available, the Simple Model was used to generate estimates for storm water runoff and mass loads. The report also contained estimates generated from local data for 1. Effluent discharges, 2. Atmospheric deposition, 3. Dredged material disposal, and 4. Loads from the Central Valley for a comparison.

Models such as the Simple Model are excellent tools for collating and evaluating available data, for education, and for proactive urban design through prediction of relative changes through time. However, the Simple Model does not take into account the influences of slope, soils and vegetation cover on hydrology, and assumes that runoff and contaminant concentrations are linearly related to land use. Furthermore, limited understanding of hydrological routing in watersheds of the Bay Area necessitated the use of CALWATER (Interagency

California Watershed Mapping Committee, 1998) as the base map and therefore the spatial resolution was relatively limited in the study by Davis et al. Thus, the loads generated using the Simple Model lack the accuracy and precision necessary for relative spatial comparisons at scales larger than development sites or sub-watersheds or for use in Bay TMDLs where a higher accuracy is needed to develop sound management goals and BMPs. One of the more important contributions that came out of the use of the Simple Model was a set of recommendations that outlined appropriate steps for improving information on contaminant loading to the Bay. The first recommendation, and the one that is relevant to this current contribution, was to map and then classify watersheds (Davis et al. 2000).

In order to estimate loads from all the urbanized and industrial, rural and open space areas adjacent to the Bay, there are seven fundamental data needs and steps to follow (concepts further developed after Davis et al. 2000):

- 1) Characterize watershed areas and drainage patterns (GIS maps of natural and modified drainages)
- 2) Develop conceptual models for each contaminant
- 3) Estimate discharge of water from each watershed area
- 4) Classify watershed areas and determine representative sampling locations
- 5) Measure concentration of suspended sediments and related contaminants
- 6) Estimate loads
- 7) Measure trends and determine the effectiveness of BMPs and other management initiatives or natural changes over time

In the Bay Area, there are a number of cities and counties and flood control or water districts that have individually characterized urban drainage patterns and catchment areas, and the Oakland Museum has begun a series of maps towards this end. SFEI is presently collaborating with the United States Geological Survey (USGS) to develop the High Resolution National Hydrography Data Set (NHD) for the Bay Area to improve our understanding of natural drainage systems in the Bay Area. A part of the budget for this storm drain project was allocated to complete a further component of the NHD (discussed in later sections of this report).

Although all these projects are ongoing, presently there is still no complete map for the whole Bay Area showing watershed and sub-watershed areas and hydrological flow paths. To develop such a map will require an understanding of both natural drainages and modified storm drainages. If the areas of wetland that surround the Estuary are excluded, the area of the small tributaries that drain to the Bay is about 6,550 km². Presently only about 44% of that area is gauged for water discharge by the USGS and its partners. Tributaries included in this calculation were San Francisquito Ck., Matadero Ck., Guadalupe R., Coyote Ck., Alameda Ck., San Lorenzo Ck. San Ramon Ck., Napa R., and Novato Ck. A lack of a suitable GIS map and discharge information will continue to hamper efforts

to characterize loads of contaminants entering the Bay from small tributaries. Furthermore, storm drain maps, when in existence, can be used for determining sources of water flowing to a known contaminated location downstream and thereby help to prioritize watersheds for management or monitoring water quality, trends or the application or testing of storm water BMPs.

In recognition of these issues, an agreement was made between SFEI and the San Francisco Bay Regional Water Quality Control Board (Regional Board) to conduct a "Storm Drain Mapping Project" (Project). Given the importance of mapping drainage systems in local small tributaries to the Bay for improving loads estimates and developing management techniques to reduce loads of storm water derived contaminants, the SPLWG took on the responsibility of oversight of the developments and work products from the Project. This report describes Project development, results and work products, data gaps, and recommendations for the future. The work products from this Project are best viewed as part of a continuum of technical and scientific development that contribute to the overall value of the series of work products that the SPLWG and SFEI Watershed Program have developed of the past three years.

Project Purpose

The purpose of the Project is to improve our understanding of drainage areas and hydrological flow paths in urban areas adjacent to San Francisco Bay. This report describes four main products that resulted through this work effort:

- 1) An inventory of digital geographic information system (GIS) coverages available from cities, counties, Special Districts, and other non-profit and for-profit groups in the Bay Area (Task 2 of the original contract);
- 2) A detailed development and evaluation of storm drain maps for a pilot area (Fremont) in the East Bay as a means for making recommendations for future efforts, data needs, and processing and development methodologies (Task 4 of the original contract);
- 3) A demonstration of results and progress report on the development of the NHD in the Bay Area (Task 1 and 5 of the original contract); and
- 4) A pilot synthesis of the NHD and storm drain maps (Task 3 of the original contract)

Project Development

Development of the Storm Drain Inventory

The original intent of the project was to inventory storm drain information that is available from the counties of Alameda and Santa Clara. After meetings with the Regional Board and other interested parties, the scope was expanded to

cover the nine incorporated Bay Area counties. Following this decision, SFEI invited a number of people to a meeting held on January 31st 2001 at the Regional Board in Oakland. At that meeting there was representation from San Francisco Estuary Institute, Regional Board, City of Oakland Public Works Agency, Santa Clara Valley Urban Runoff Pollution Prevention Program, Eisenberg, Olivieri, & Associates, City of Hayward, Santa Clara Valley Water District, City of Fremont, Alameda Countywide Clean Water Program / County of Alameda Public Works Agency, Oakland Museum, Clean South Bay, and William Lettis & Associates. One of the topics of discussion and outcomes of the meeting was a final list of the types of information and GIS data layers that are useful for tracking illicit discharges and improving our understanding of non-point sources, transport, and loads of contaminants entering the Bay from small tributaries.

Following that meeting a data inventory questionnaire and a data inventory request form (Table 1) was developed and reviewed by interested people that included meeting attendees from the January 31st meeting. This was then sent out to potential data stewards that included suggestions from ABAG.

Response to the mail out was disappointing. Only about 15% of the 53 groups surveyed returned the questionnaire. In hindsight, part of the reason for the limited response was probably that information for a number of layers was requested that were only tangentially associated with the assessment of existing digital storm drain information. This may have left groups confused about the project objectives and less motivated to respond.

Perhaps a better approach would have been to prioritize cities and counties that have storm drainages that discharge directly to the Bay margin and work with them directly face to face. Other cities, for example, in the middle and upper parts of watersheds in Alameda County and Santa Clara County would be less important because storm water flows from these storm drainages are channeled through stream systems that are captured by other mapping efforts such as NHD.

Choosing the Pilot Area

After the development of the project scope, a meeting was called to discuss the benefits of the GIS portion of the Project, how it should be developed, what it should include and where it should be focused. Groups represented included local illicit discharge regulators from Oakland, Hayward, Fremont, and San Jose, the Alameda County Clean Water Program, public environmental advocacy, the Santa Clara Basin Watershed Management Initiative, the Oakland Museum and William Lettis & Associates because of their prior work on East Bay storm drain maps, Regional Board staff, and SFEI staff. The group agreed that such a GIS would be useful for meeting the Project purposes. It was also decided that the Project scope could only provide for a GIS in one pilot study area. Oakland and Fremont were considered because of the potential existence of

Table 1. Storm drain mapping inventory form.

| San Francisco Bay Regional Storm Drain Data Inventory Request Form | | | | | | | |
|---|---------------|---|--|---------------------|---|--|--|
| To be provided by the person completing the request form | | | | | Date: | | |
| County: | | City: | | | | | |
| Organization: | | Name: | | | | | |
| Title: | | Email: | | | | | |
| <i>In the interest of your time, we have identified the highest priority data sets for the Regional Storm drain Data Inventory. These layers are the first sixteen that have been shaded. At a minimum, please provide information for these layers where available. Any information for the remaining twenty-five data sets will be greatly appreciated if possible.</i> | | | | | | | |
| Data Set | File Name | Data Description | Format (Paper, ArcView shapefile, ArcInfo coverage, MapInfo mif, etc.) | Meta-data (Yes, No) | Data Share Agreement Required (Yes, No) | Data Location (agency, address) | Contact Person (phone, email) |
| EXAMPLE storm drains | strmdrain.shp | stormdrain location, flow direction, inlets, outlets, elevation | shapefile | Yes | No | Alameda County PWA 399 Elmhurst St. Hayward, CA 94544 | Your Name, GIS Person (510) 123-4567 name@acpwa.mail.co.alameda.ca.gov |
| stormdrains & inlet/outlet locations | | | | | | | |
| manhole covers | | | | | | | |
| sewer lines | | | | | | | |
| hydrography | | | | | | | |
| topography | | | | | | | |
| topographic watershed boundaries | | | | | | | |
| Data Set | File Name | Data Description | Format (Paper, ArcView shapefile, ArcInfo coverage, MapInfo mif, etc.) | Meta-data (Yes, No) | Data Share Agreement (Yes, No) | Data Location (agency, address) | Contact Person (phone, email) |

Table 1 continued.

| | | | | | | | |
|---------------------------------|------------------|-------------------------|---|----------------------------|---------------------------------------|--|--------------------------------------|
| engineered watershed boundaries | | | | | | | |
| digital elevation model (DEM) | | | | | | | |
| political boundaries | | | | | | | |
| parcel data | | | | | | | |
| roads | | | | | | | |
| business names and addresses | | | | | | | |
| hazardous waste handlers | | | | | | | |
| hazardous waste generators | | | | | | | |
| hazardous materials data | | | | | | | |
| NPDES permittees | | | | | | | |
| Data Set | File Name | Data Description | Format (Paper, ArcView shapefile, ArcInfo coverage, MapInfo mif, etc.) | Meta-data (Yes, No) | Data Share Agreement (Yes, No) | Data Location (agency, address) | Contact Person (phone, email) |
| waste water treatment plants | | | | | | | |
| known illicit discharges | | | | | | | |
| industrial inspection sites | | | | | | | |

Table 1 continued.

| | | | | | | | |
|-----------------------------------|------------------|-------------------------|---|----------------------------|---------------------------------------|--|--------------------------------------|
| impervious surface area | | | | | | | |
| land use/ land cover | | | | | | | |
| instream structures | | | | | | | |
| discharge measurements | | | | | | | |
| flow regime | | | | | | | |
| flooding | | | | | | | |
| wetlands | | | | | | | |
| Data Set | File Name | Data Description | Format (Paper, ArcView shapefile, ArcInfo coverage, MapInfo mif, etc.) | Meta-data (Yes, No) | Data Share Agreement (Yes, No) | Data Location (agency, address) | Contact Person (phone, email) |
| water quality | | | | | | | |
| bacterio- logical | | | | | | | |
| macro- invertebrate indices | | | | | | | |
| water quality sampling sites | | | | | | | |
| habitat types | | | | | | | |
| fish census data | | | | | | | |

Table 1 continued.

| | | | | | | | |
|--|------------------|-----------------------------|---|---|---|--|--------------------------------------|
| general plan | | | | | | | |
| jurisdictions (land management) | | | | | | | |
| mineral resource data | | | | | | | |
| erosion and landslides | | | | | | | |
| Data Set | File Name | Data Description | Format (Paper, ArcView shapefile, ArcInfo coverage, MapInfo mif, etc.) | Meta- data (Yes, No) | Data Share Agreement (Yes, No) | Data Location (agency, address) | Contact Person (phone, email) |
| seismic hazard zones/ faults | | | | | | | |
| fire stations | | | | | | | |
| schools | | | | | | | |
| watershed groups | | | | | | | |
| Please provide information for any additional data layers that you feel should be included in the Regional Storm Drain Data Inventory | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

quality storm drain data and the willingness to share data and participate in the Project.

A follow up meeting was held between the cities of Oakland and Fremont, the Alameda County Clean Water Program, William Lettis & Associates, and SFEI staff. The meeting focused on the selection of a specific pilot study area, existing GIS layers found critical to meet Project purposes, software and hardware requirements, data sharing agreements, and GIS structure.

Development of the pilot was by far the most labor-intensive portion of the storm drain mapping project. Initially the concept was to model storm water drainage areas based upon inflow points into the storm drains network. This would be done by taking modified DEMs in urban areas (modified to favor the preference of water to flow in streets), and generating drainage areas for inflow points. Then manual editing would be used to correct those drainage areas where necessary. Each drainage area would be linked to a specific inflow point, and each inflow point to the specific series of down stream storm drains. This would allow the user to select an upstream point, and see what pipes water would run through to move down stream, or select a downstream point and see where all the water to that point was coming from.

The primary problem that arose was the lack of inflow points from the Oakland GIS. All discussion with the Oakland group were initially positive; however, Oakland does not have these points in its current GIS (perhaps they were lost or the files became corrupted). On this basis, it was decided by the Project team to use the Fremont data set for the pilot project.

Development of the Pilot Storm Drain GIS

SFEI used existing data to test methods for the creation of, attribution of, and generation of urban drainage delineations for storm drain information. Fremont was chosen as the pilot study area because of the quality of their GIS layers. SFEI obtained a broad range of information relating to storm drain mapping from the City of Fremont. This included storm drains (in two separate layers), curb inlets, drain inlets, drain outlets, sewers, streams, water features, fire stations, schools, fault lines, contours, and political boundaries. These coverages were provided as ArcView 3.2 shapefiles, with a complete metadata dictionary. SFEI converted the data provided into an ArcInfo 8.0 coverage format, and reprojected the coverages into the Universal Transverse Mercator projection.

Using a combination of automated and manual attribution, the storm drain features were attributed with the ID of the feature they flowed to. This attributed coverage was used to generate urban watersheds for a portion of the City of Fremont. These watersheds were compared with the urban watershed delineations produced with field verification by William Lettis & Associates.

Catchment areas were then mapped by hand for a small segment of Fremont using a combination of aerial photography and contour lines.

The drain outlets coverages provided by Fremont were used to define the final pour point of subwatersheds. Additionally two other urban catchment area coverages were produced. One was produced using the attributed storm drains and the standard USGS 10 meter Digital Elevation Model (DEM) using ArcInfo's automated watershed generation function. The second coverage was produced using the same method substituting a USGS 10 meter DEM that had been modified to favor the use of roads as flow paths for water. All three urban subwatershed delineations were compared with the urban watershed delineations produced by William Lettis and Associates.

Development of the NHD

The National Hydrography Dataset (NHD) is a comprehensive set of digital spatial data that contains information about naturally occurring and constructed bodies of water, natural and artificial paths through which water flows, and related hydrographic entities (USGS, 2000). Within the NHD, features are combined to form reaches, which are coded using the USEPA Reach File (RF3), and which provide a framework for linking (or geo-coding) water-related data to the NHD surface water drainage network. These linkages enable the analysis and display of these water-related data in upstream-downstream order. These reach codes also provide a means for determining upstream and downstream flow. The reach codes provide the means to generate more accurate upper watershed delineations, which are critical to effective assessment of the sources, pathways and loadings of contaminants to the Bay.

SFEI worked with the United States Geological Survey (USGS) to develop pilot 24K NHD Storm Drain layers for the Coyote and San Francisco Bay catalogue units. SFEI was responsible for the editing and cleaning of the 24K DLG blue lines to prepare them for NHD processing. This included the removal of neat lines, edge matches between quads, and the creation of stream centerlines. USGS then conflated the 100K NHD reach codes to the new 24K coverage, editing lines and stream names and adding new reach codes where necessary.

Development of the Pilot Synthesis of the NHD and Storm Drain Coverages

Accurately mapping a watershed boundary requires mapping not only the upper watersheds (typically in a less modified state) based upon topology, but also of the urban and flat land areas through other techniques. As a demonstration of how existing urban and topologically based watershed delineations might be integrated, a demonstration synthesis product was created for the East Bay. The goal was to combine urban delineations generated by William Lettis & Associates with watershed delineations generated by SFEI. SFEI used the USGS 10-meter DEMs and the revised DLG blues line generated for

the San Francisco Bay CU 24K NHD effort (funded by Alameda Countywide Clean Water Program).

Results

Storm Drains GIS Inventory

An inventory of existing digital information on storm drainages in the Bay Area was collected from many cities in the nine-county bay Area (Table 2). The focus was narrowed to collecting information on storm drain line and point coverages as well as existing watershed delineation efforts (more closely aligned with the original contract). Topographical information was also recoded because of its potential use as the basic data required for improvement of the definition of watershed boundaries across the Bay Area. A discussion of existing coverages is made the following paragraphs.

Software and format

Cities and counties in the Bay Area are presently utilizing a range of software alternatives for building and displaying digital storm drain information (Table 2). The computer aided design (CAD) software application AutoCAD, developed by Autodesk Inc, San Rafael, CA appears to be the most common software application. AutoCAD is a cartographic tool used mainly for design and display in engineering applications, hence, many of the city and county engineering departments have used this tool for many years and have accumulated expertise. Microstation by Bentley is another CAD software application used in the Bay Area for engineering design and viewing of storm drain information. Microstation tends to play little brother to AutoCAD in terms of worldwide users (300,000 versus 4,000,000), however recent reviews suggest that Microstation version 8 has many strengths. Of interest here, Microstation V.8 can read and write in both its native format DGN files and in AutoCAD DWG file format.

In some cases there is reluctance and in other cases, a lack of recognized need, money or staff time to convert CAD drawings to geo-rectified GIS systems. However, some cities and counties in the Bay Area have developed or are presently developing geographic information systems (GIS). GIS differs from CAD in several important ways. Firstly, the information is geo-referenced spatially to a real world coordinate system such as stateplane or Universal Transverse Mercator (NAD27 or NAD83). Secondly, the attributes describing the points, lines, and polygons in CAD systems are often written as text directly onto the drawings. This may be quite practical for display purposes but this makes conversion from a CAD to a GIS format time consuming. In a GIS, attributes for each point, line, or polygon are stored in tables that can be accessed by a series

Table 2. An inventory of existing information relevant to storm drain and watershed boundary mapping in counties and cities of the Bay Area.

| County / City | Contact person | Storm drains | | | | | | | | Watershed boundaries | | Topography / DEMs | | |
|-------------------------|--|--------------------------------------|--|------------------------|------------------|-----------------|---------------------|--------------|---------|----------------------|-----------------------|-------------------|-------------------------|-------------------------------|
| | | Location | Software / format | Diameter | Invert elevation | Inlets/ outlets | Routing/ networking | Catch basins | Quality | Location | Method/ source | Location | Method/ source | Scale/ resolution |
| Alameda | Paul Modrell 510 670 5782 | | | | | | | | | | | East Bay plain | 1996 Aerial photography | 1:400 2 foot contours |
| Fremont | | | | | | | | | | | | | | |
| Livermore | Melinda Sunnarburg 925 373 5264 | All | AutoCAD, planning to convert to GeoMedia | Y | Y | Y | N | Y | 6 | N, as needed | N/A | All | Aerial May 2001 | 2 feet city, 5 feet surrounds |
| Pleasanton | Steve Wood 925 9315073 | All | ArcView 3.2 | All, >12 inch | Y | Y | Y | Y | 1 | Y | 3 | All | Aerial May 2001 | 2 feet city, 5 feet surrounds |
| Contra Costa | Liz Klute | All cities Except Richmond late 90's | Microstation DGN | N | N | N | N | Y | 4 | Y | Flood control mapping | All | Aerials 2000 | 10 feet |
| Antioch | Chris Alvarez | All | Paper, Arc 8.1 | All, 12 in and greater | Y | Y | Y | Y | 3 | Y | 3 | All | ? | ? |
| Brentwood | Edelyn Baula www.ci.brentwood.ca.us | All | AutoCAD DWG, ArcView | All, 12 in and greater | N | Y | N | N | 3 | N | N/A | All | Aerial Dec'99 | 5 feet flat 10 feet steep |
| Concord | Shae Halligan | All | ? | >36 in or larger | ? | ? | ? | ? | ? | | | | County aerial | ? |
| Danville | Renee Collins | All | GeoMedia | All, 12 in and greater | N | Y | N | Y | 3 | N | N/A | All | County Aerial 2001? | 5 feet |
| Hercules | Gary Slone | All | Microstation DGN / Arc8.1 | All, 12 in and greater | N | Y | Y | N | 3 | N | N/A | All | ? | 10 feet flat 50 feet steep |
| Lafayette | | | | | | | | | | | | | | |
| Martinez | Jo Enke | All | Paper AutoCAD Schematic | N | N | N | N | N | 4 | As needed | N/A | ? | ? | ? |
| Oakley | Jason Bogan | All | Paper | N | N | Y | N | Y | 5 | N | N/A | All | County Aerial 2001? | 5 feet |
| Pinole | Bill Mattick 510 741 2065 | All | AutoCAD? shape file | >12 inch | Y | Y | Y | N | ? | ? | ? | ? | Aerial photos? | 1:400 1:200 |
| San Ramon | Amy Hernandez 925 973 2611 | All | Microstation DGN | >12inch | Y | Y | ? | ? | ? | ? | ? | All | Contours | ? |
| Walnut Creek | Joan Nickins 925 9435899 | All | AutoCAD | Y | ? | Y | Y | | Good 3? | | | All | ? | ? |
| Marin | | | | | | | | | | | | All | Aerial 1997 | 5 feet |
| Mill Valley | Wayne Bush | All | ArcView | All, 12 in and greater | N | Y | N | N | 4 | | | | | |
| Mill Valley, Coyote Ck. | Wayne Bush, and Marin County (Liz Lewis and Trace Clay) | Planned pilot project | ? | All, 12 in and greater | Y | Y | Y | ? | 1 | ? | ? | All | Aerial 1997 | 5 feet |
| San Rafael | Bill Voigt | All | AutoCAD | All, 12 in and greater | N | Y | N | Y | 3 | Y | 3 | All | Aerial 1997 | 2 foot flat 5 foot steep |
| Tiburon | Pat Echols | None but planned | | | | | | | | | | | Aerial 1997 | 5 feet |

Table 2 continued.

| | | | | | | | | | | | | | | |
|------------------------|---|-----------------------------------|---|-------------------|-------------|---|-------------------|--------------------------|---------|--------------|------------------------------|-----|---|---|
| Novato | Fred Isla | 80% | AutoCAD + Excel | All | Y | Y | N but can be done | N but can be done | 5 | N but needed | Will use topo + storm drains | All | Aerial 1960s latest 1997 | 1 foot flat 5 foot steep |
| Napa | | | | | | | | | | | | | | |
| American Canyon | Mark Billings Cheryl Braulik | All | AutoCAD | ? | ? | Y | ? | ? | ? | ? | ? | All | ? | 1":200' major and minor contours |
| San Mateo | | | | | | | | | | | | | | |
| Redwood | | | | | | | | | | | | | | |
| Santa Clara | | | | | | | | | | | | | | |
| San Jose | Roberta Melleno 408 277 4293 Tim Hayes ext 4346 | All | Microstation and oracle data base MGE ArcInfo | 12 in and greater | Y | Y | Y | Y | 2 | N but needed | N/A | N | N/A | N/A |
| Palo Alto | Ken Torke 650 3292598 Matt Raschke ext 2469 | All | Oracle data table, Binary long object files | 12 in to 8 feet | Y about 40% | Y | Y | Y some modeled as needed | 1, 2, 3 | N | N/A | All | 1993 Aerial stereo digitized and analyzed | <1 foot spot elevations on street lines etc |
| Solano | | | | | | | | | | | | | | |
| Benicia | Michael Throne | N | | | | | | | | | | | | |
| Vallejo | | All expected completion June 2002 | AutoCAD, MapInfo | >12 inch | Y | Y | Y | Y | 1 | Y | 3 | All | Aerial photo | 2 foot contours |

Location: All-whole city area, Part-only partially digitized, or in progress

Quality: 1 GPS field verified, 2. Digitized, verification ongoing, 3. Digitized, verification in near future, 4. No verification, 5. Schematic only, 6. Near real location schematic with ongoing update using as-built drawings and field verification at the non-GPS level

Catch basins methodology: 1. Pipe networks and elevations, 2. Topography, 3 Combination

of integrated tools and can be mathematically and statistically manipulated in virtually any way the user desires.

ArcView by ESRI is an example of a fully featured desktop GIS that has significant data collection, spatial analysis and cartographic production capabilities. It contains its own programming language for customization and production purposes. ArcView has the capabilities to fully interact with all types of GIS data available. Analysis functions include a wide range of geo-processing tools, tabular database functions, and data creation and modification capabilities. With software add-ons ArcView can support extensive raster and image processing capabilities. The main disadvantage with ArcView is that it is designed for the high end user rather than the casual user. ArcView is currently being utilized by Contra Costa County in an extensive storm drain mapping effort. Arc 8.1, ESRI's latest software version is a combination of tools that were previously contained within ArcView and ArcInfo with the addition of some new features. Arc 8.1 utilizes a new data model that is more effective at storing spatial data and the metadata associated with it. Additionally the tools associated with managing spatial and metadata have been greatly enhanced. The ability of the software to link directly to many of the newly emerging spatial/relational database technologies has been greatly enhanced. The user interface has been redesigned in order to make the software more user-friendly. Arc 8.1 also is now capable of doing reprojection on the fly, so that data from different source projections and organizations can be easily viewed and compared.

GeoMedia by INTERGRAPH is another GIS solution. GeoMedia is described by the cities that are using it in the Bay Area as a mid level GIS tool for data integration. The benefits of GeoMedia include a windows style platform and the ability for the software to cope with a wide variety of files formats. With GeoMedia the user can define, and access, all the features of the data that are held in another product's format. This means that data from most other GIS systems or databases can be used in GeoMedia without changing it from its native format. In theory, these two features give the product the ability to integrate into a workplace without the need for a paradigm shift, file conversion and decrease in productivity. In addition GeoMedia can be used as an intranet server for building, displaying and analyzing spatial information such as stormwater and wastewater sewer lines and easily interfaces with the web using an open architecture.

MapInfo by MapInfo Corporation is yet another "mid level" GIS tool. Its advantages over ESRI products include a relative simplicity, a simple to use attribute table structure, the ability to store areas, lines, points, and text in the same table, and good re-projection utilities. One of its downfalls in the past has been its inability to cope with AutoCAD DWG & DXF files and this is perhaps the reason that it is less commonly used for applications of urban geography.

Relational databases such as Oracle and Informix have recently added functionality that allows for the storage of spatial information. Although these database tools often lack some of the spatial manipulation functions that come with common GIS

software packages, they are easy to build custom applications for. Some organizations will build custom means of storing spatial information into these databases to expand upon, or completely replace their spatial data storage abilities. Because the spatial features are stored within a relational database, it is easy to relate other data, such as water quality or pipe maintenance information, to those features.

With such a diversity of data formats and software packages in use within the Bay Area, it will likely be difficult to provide a tool to a user that is compatible with all the existing systems. Although a tool could be developed for a single software package, such as ArcView, and then provided to users, there may be resistance to installing a new software platform if they have existing infrastructure. Some organizations will not want to invest the effort to train staff, or commit to maintaining a new piece of software over the long term. It seems clear that any tool developed for storm drain information should be platform independent, and have low maintenance and training requirements. Additionally there must be a means of accepting data from, and exporting data to, the great variety of existing software packages and platforms.

Differences in Accuracy

Digital storm drain information has been collected by cities and counties for a variety of reasons, for example, the development and maintenance of the networks, resource inventory, new development or redevelopment approval, tracking illicit discharges, and monitoring and modeling the quality of urban runoff. Given the wide variety of applications and the wide variety of software platforms for developing, displaying and sharing the data, there should be no surprise that data have a wide variety of quality.

The quality of the data relates to four main issues: source, field verification, frequency of update, and software platform. In addition, the quality is often influenced by the availability of staff time and resources, and staff expertise. The most common method used by groups in the Bay Area for obtaining digital files is to digitize infrastructure maps developed from as-builts. These can vary in age and frequency of update. For example, if a city is rapidly urbanizing, older infrastructure maps may have been digitized or developed and stored in CAD systems, but staff time or resources can limit file updates as development continues or accelerates. At the other end of the spectrum, where original maps are deemed to be too outdated, some cities are opting to build digital coverages “from the ground up” using GPS field data collection and the outdated maps are only used, if at all, as a guide on how to place effort during the new field data acquisition process.

Although new data collection might be the preferred method, there are no standards available for helping cities and counties to decide exactly what type of data to collect, which tools are best, what accuracy to aim for, or how to standardize metadata. As a result, even new data collection has a range of accuracies and may not be consistent between cities within one county, let alone between counties.

Setting aside the differences in GIS versus CAD software platforms, the existing data in the Bay Area varies in quality from: 1. GPS field verified, 2. Digitized, verification ongoing, 3. Digitized, verification in near future, 4. No verification, 5. Near real location schematic with ongoing update using as-built drawings and field verification at the non-GPS level, 6. Schematic only. In addition, metadata are not always available because they were never recorded digitally or because of staff turnover and loss of accumulated knowledge. Naturally, there are exceptions to these comments but in conclusion, digital storm drain information in the Bay Area is of variable quantity or quality.

Watershed Boundaries and Topographic Information

In spite of varying coverage and reliability of storm drain infrastructure maps for determination of pathways of water flow, many cities and all county flood control districts have developed maps of watershed and sub-watershed boundaries. These are usually developed using 2 or 5 feet topographic contours derived from aerial photography and stereographic analysis and storm drain information where it exists (Table 2). There is discussion on the accuracy of such maps (e.g., Randall and Buchan, 2000). They suggest that boundaries will change depending on the size and intensity of the rainstorm (be it a 2-year event or a 100-year event). They also demonstrate that boundaries are changing in watersheds that are urbanizing although the change has been <1% in some cases (e.g., Coyote Ck. and Guadalupe R. over the past 20 years). Nevertheless, ongoing reevaluation as urbanization continues is necessary especially when the definition of such boundaries may vary depending on the application.

Use of Existing Information in the Context of Sources, Pathways and Loadings

At present, there are not sufficient storm drain coverages yet developed with suitable quality and metadata to complete a process of regional coagulation of existing maps for the purpose of accurately defining natural and modified hydrography across the Bay Area local watersheds that are directly tributary to the Bay. This implies that if a regional analysis is to be done on the flow of water and contaminants from urban watersheds surfaces, an alternative method that integrates storm drain coverages (where they exist) with topographic information and existing watershed boundaries delineated by county flood control districts remains the best solution. Subsequent sections of the report discuss methods and practical issues in both the development of storm drain information and the definition of watershed boundaries as they relate to the flow of water and waterborne contaminants from urban areas to the Bay.

Over the past five years, the Oakland Museum and Janet Sowers of William Lettis & Associates have been developing a storm drain map series in collaboration with cities and counties around the Bay Area (Oakland Museum 1997; 1999; 2000). This series of maps is an example of a suitable product for sources, pathways and loading evaluation. This series combines modern hydrography (storm drains and natural channels), water boundaries, present and historical shorelines, tidal marshes, beaches and willow groves. The maps include creeks having a minimum of 0.2 km² of watershed area and storm drains of 24 inch (610 mm) and greater diameter. The location of storm

drains and present day creeks were compiled from city and county maps of the storm water runoff system and confirmed with field inspection. In this way, effort was made to produce accurate maps however the authors suggest an accuracy of better than 100 feet (30.5 m) either side of a creek or drain feature. In comparison, the USGS DLG blue lines (24k NHD) have an accuracy of 40 feet (12.2 m) either side of a line feature. Presently the focus of William Lettis & Associates has been on map development in the East Bay, however there are proposals to carry out similar mapping efforts in the South Bay and San Mateo.

Pilot Storm Drain GIS

The goal of the pilot storm drain GIS effort was to develop and test methodologies for storm drain mapping. The production of a storm drain application was never within the scope of the original contract. The effort to produce a storm drain application provided an opportunity to test methodologies, and identify data requirements and gaps. These tests provided lessons that helped define recommendations (Task 4 and 5 of the original contract) for how to develop storm drain information on a regional level. A few of the lessons learned are stated in the following paragraphs.

When starting attribution of storm drains to define catchment areas, the outflow point coverage was utilized to define the bottom most point of the catchment. SFEI made the assumption that the outflows mapped were generated when a smaller series of storm drains comes together and connect to a channel or stream at an outflow point. However, in some cases streams turned into culverts, and then back into streams. This caused double counting/attribution of some portions of the storm drain network. Trying to define the storm drain network in terms of stream order is very challenging, and an effort to assure usable outflow points, or to provide a clear definition of catchment areas needs to be undertaken.

Some of the storm drain features did not connect to the rest of the network. A process was developed to deal with these disjunct features. Still there were some features that could not be included without extensive local knowledge or field verification.

When comparing catchment areas generated by hand, and by automated processing with William Lettis & Associates urban watershed coverage, it is clear that automated processing using DEMs is not effective in urban areas. Digitization from aerial photos, with high-resolution contours and field verification is the best way to delineate urban drainages.

National Hydrography Data Set

The 24K NHD Catalogue Unit (CU) for Coyote has been completed in ArcInfo coverage format (Figure 1). The catalogue unit can be obtained by contacting SFEI and is displayed on SFEI's EcoAtlas On-line (www.ecoatlas.org) and can be queried for

reach codes. The San Francisco Bay and San Francisco Coastal Southern CU will be completed by the end of May 2002. SFEI is currently undergoing an effort to develop funding for the three remain Bay Area CUs (Tomaes-Drakes Bays, San Pablo Bay, and Suisun Bay CUs).

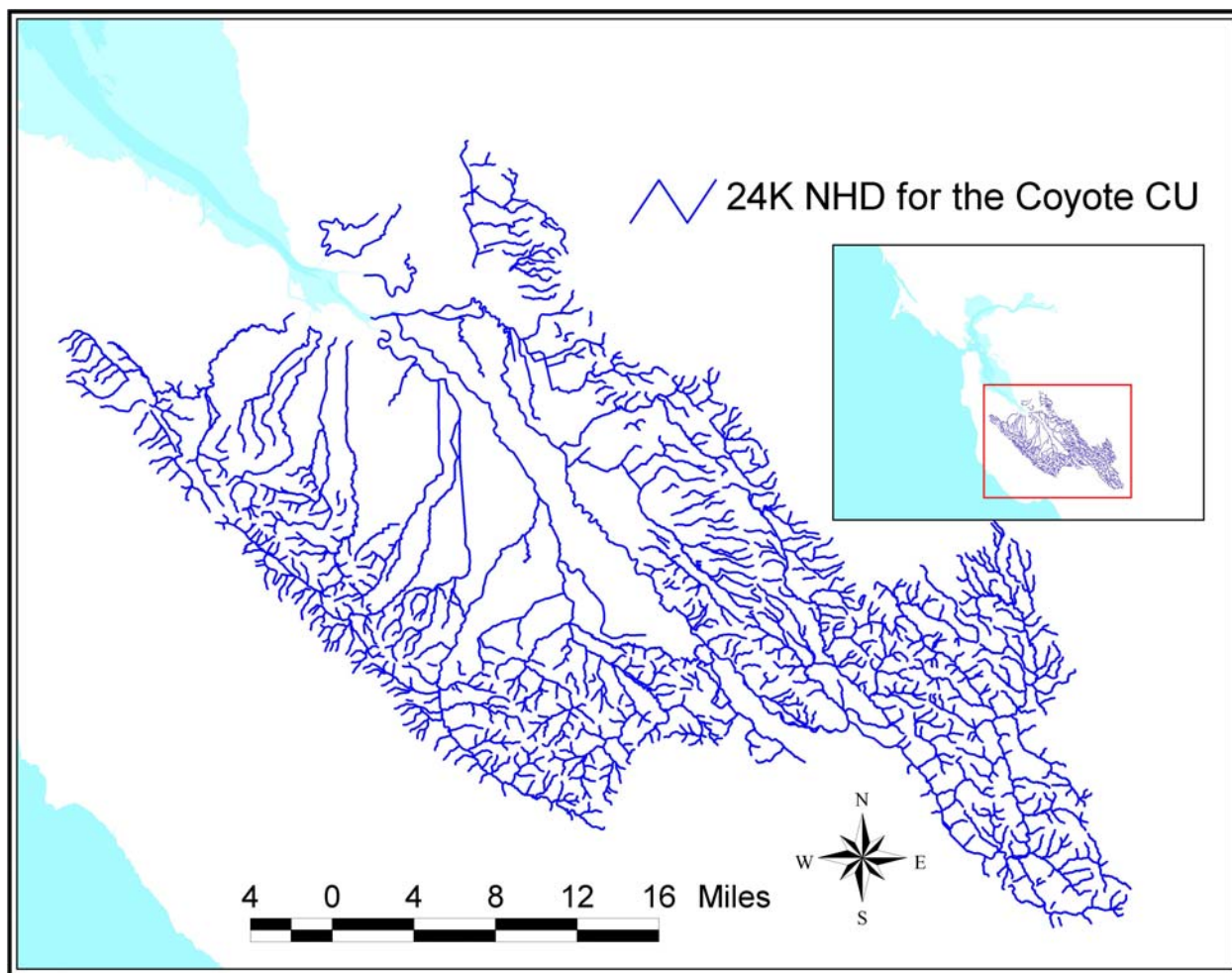


Figure 1. The 24K NHD Coyote Catalogue Unit.

Pilot Synthesis of NHD and Storm Drain Coverages

The synthesis effort included all of the Bay Area. For the Coyote and San Francisco Bay CUs, the 24K NHD effort was used to generate pour points (Figure 2). For all other Bay Area catalogue units, manually attributed USGS 24K blue lines were used. Watersheds were generated down to the upper limits of the Baylands margin (the reasons for this will be further explored in the discussions section). The William Lettis & Associates urban watershed delineations for the East Bay were then added to the

coverage (Figure 3). Higher resolution watershed delineations for Alameda County (including urban and upper watershed delineation) were provided by Alameda County Clean Water Program, and integrated with the coverage as well (Figure 4). Where readily available, high-resolution boundaries from SFEI's detailed watershed assessment efforts were included as well (Figure 5). The result is a draft regional watersheds map (Figure 6). The draft layer can be viewed and queried on SFEI's EcoAtlas On-line demonstration (www.ecoatlas.org).

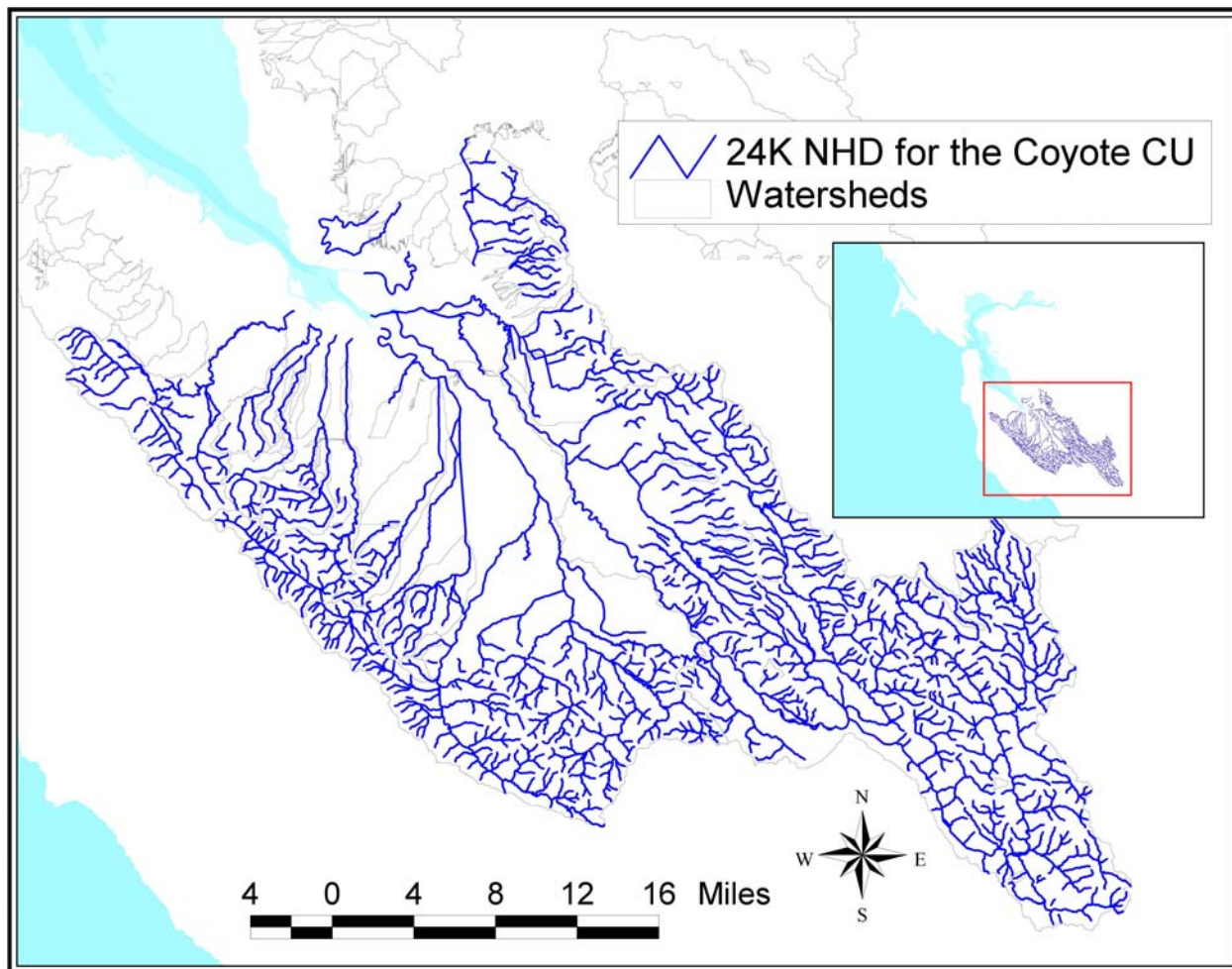


Figure 2. SFEI's watershed delineations and the Coyote CU.

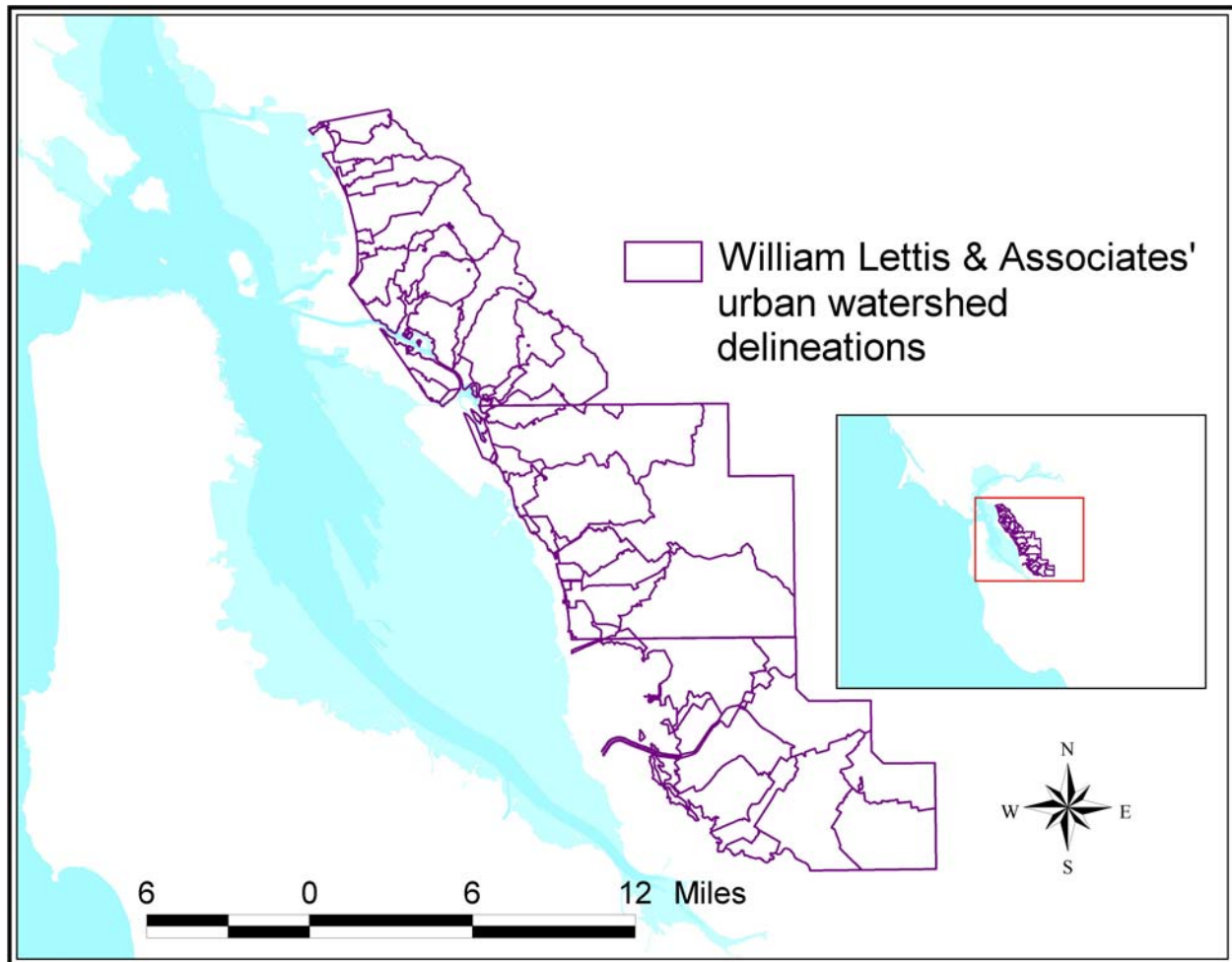


Figure 3. Urban watershed boundaries.

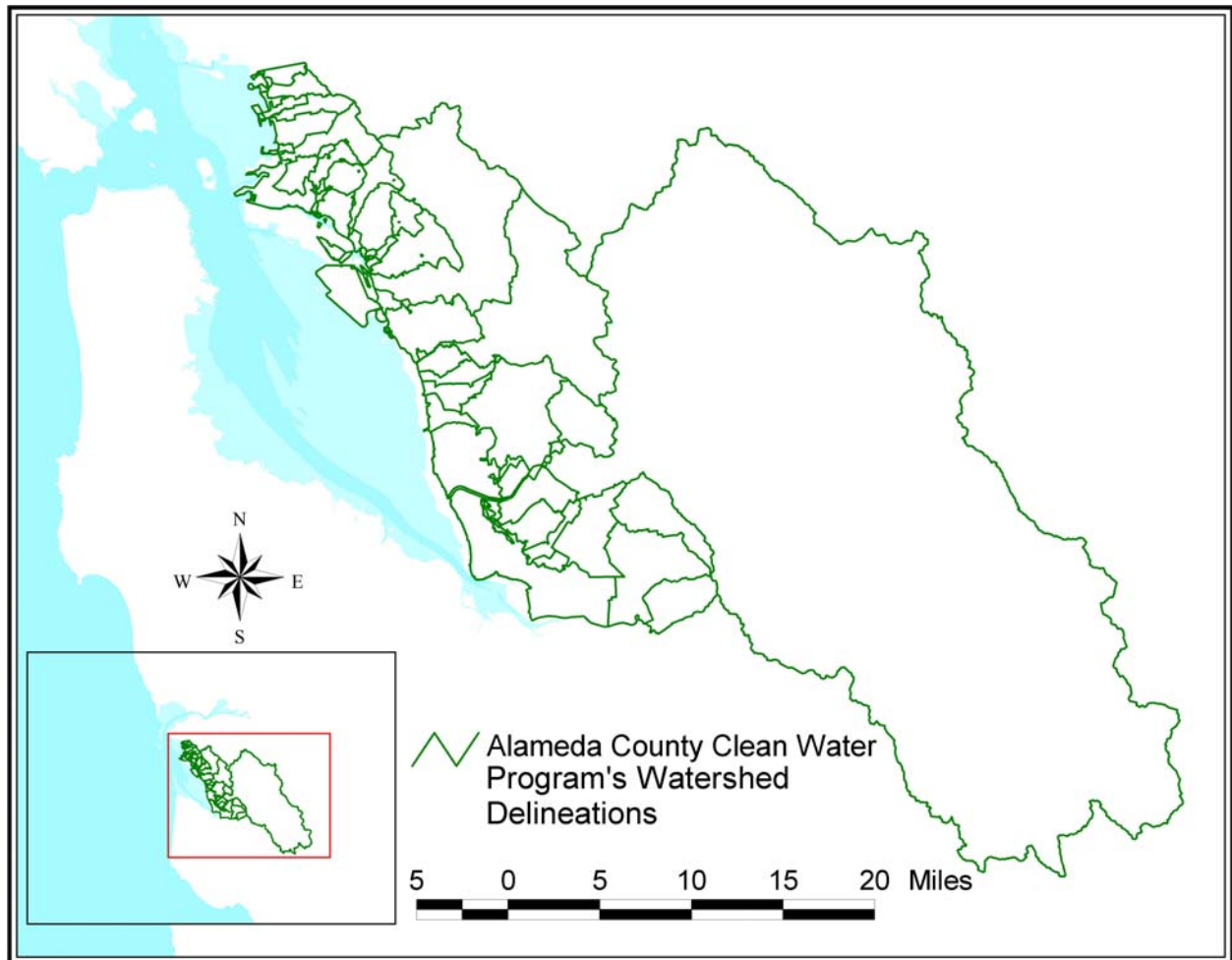


Figure 4. Watershed Boundaries provided by Alameda County Clean Water Program.

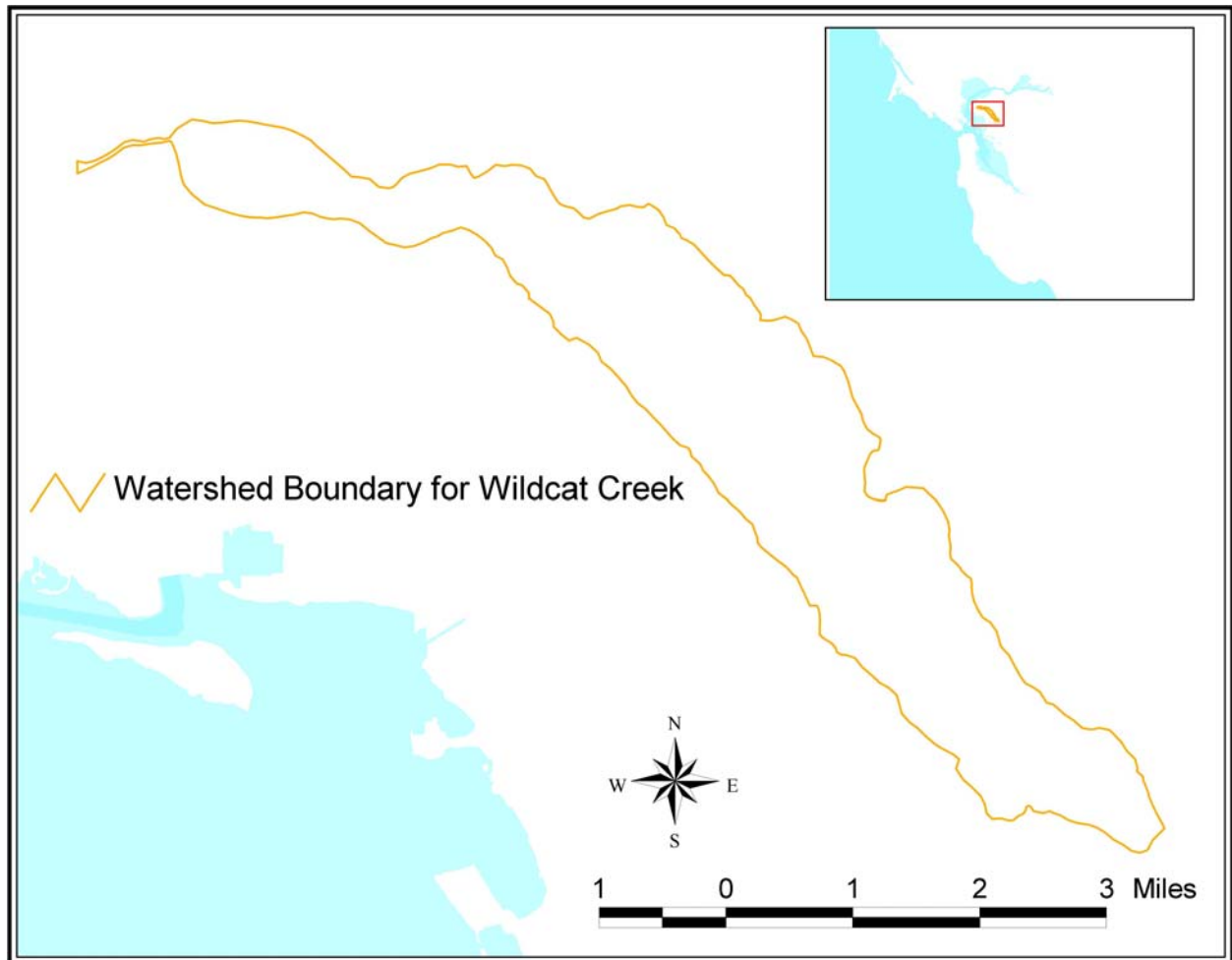


Figure 5. Example of a high-resolution watershed boundary (Wildcat Creek, Contra Costa County).

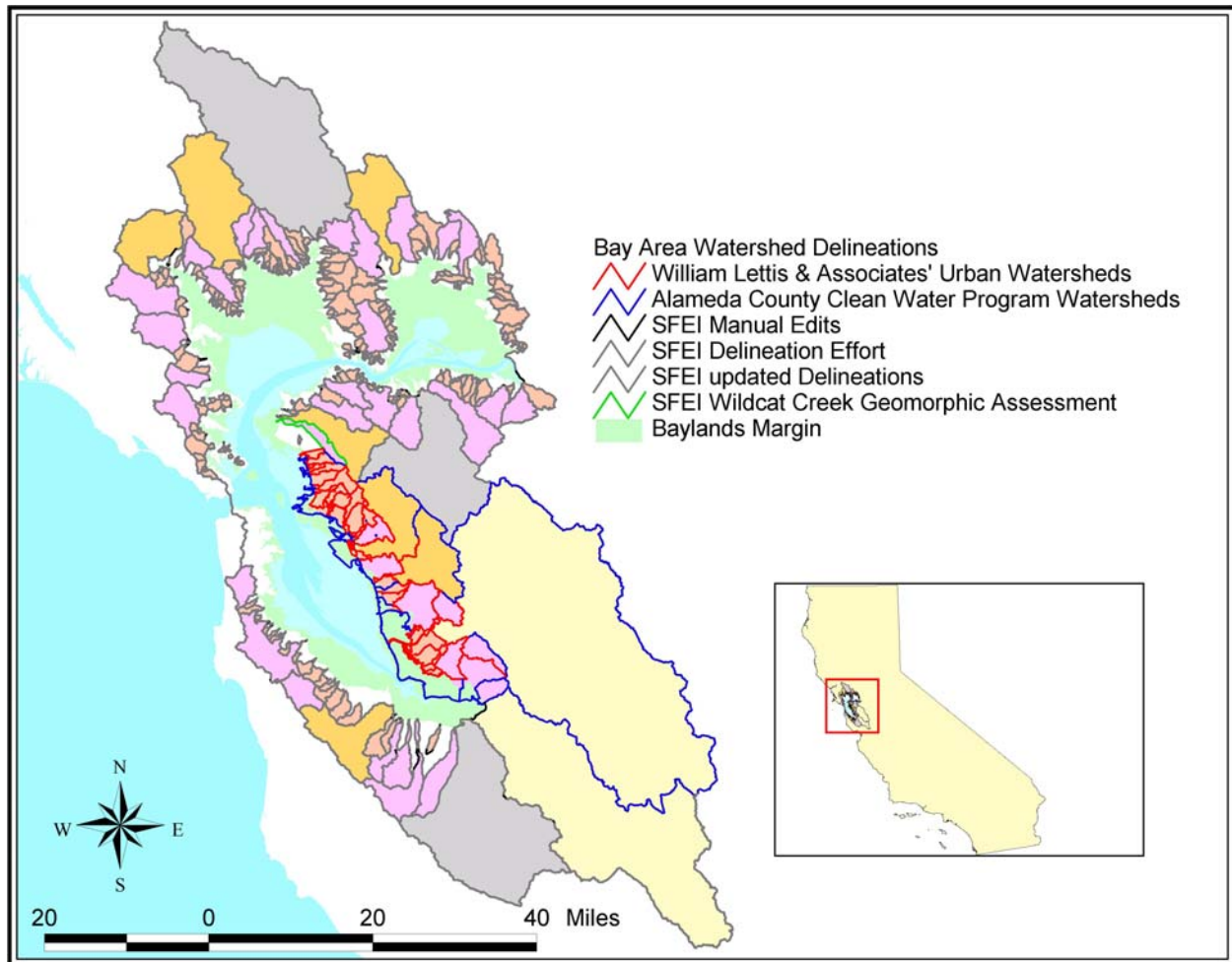


Figure 6. Urban and natural watershed boundary synthesis effort.

Discussion

What Defines the Bottom Pour Point of a Watershed?

The effort to generate watersheds using 10-meter DEMs and various streamline sources highlighted the need for clarification of the definition of the bottom most point of a watershed. Traditionally it has been the point at which the flow has entered the Bay. However, in some cases this may not be true. Tidal influence can have a significant effect on determining a stream or creek's point of outflow. In some cases, when the tide is going out the stream might flow directly down it's primary channel, through the wetlands, and into the Bay. However, on the flood tide, the tidal energy may force the stream or creek's flow back up the channel and out through a series of smaller of channels distributed throughout the wetland. Sampling at the point where that channel enters the Bay may not be an accurate means of sampling contaminant flow from the associated watershed in the context of sources, pathways and loadings of sediments and related contaminants.

One alternative is to define the bottom most point of a watershed as the point where a stream or creek meets tidal influence. However, this can create some interesting issues as tidal influence can reach a large distance up some streams and storm drains. When this is the case, it follows that a number of much smaller networks pouring directly into the tidally influenced channel get classified as individual watersheds. The compromise used for this watershed delineation effort was to use the Baylands margin (EcoAtlas, San Francisco Estuary Institute 1997, Oakland CA) to determine the bottom most pour point of a watershed. Wherever a confluence intersected the Baylands margin, that point was used as the bottom point of the watershed. That way artificial watershed determinations in an area where flow direction is so highly variable were not created.

24-inch Drains Versus 12-inch Drains

Our assessment suggests 24-inch storm drains (Figure 7) are suitable for creating watershed delineations in urban areas. Smaller diameter (e.g. 12-inch) storm drains can prove very useful in this process, but they are not required. Using the proper method of ground verification to determine the extent of a storm drain's watershed, the difference between using 12-inch and 24-inch pipes should be nominal.

The use of 12-inch storm drains (Figure 7) becomes more important when the users want to determine catchment areas within the 24-inch defined storm drain watersheds. A smaller 12-inch or less storm drain feature draining directly into a stream or channel might justify it's own catchment area. With such a large number of catchment areas to delineate, 12-inch storm drains would allow better prioritization of which areas require in-depth field verification.

The use of 12-inch storm drains becomes critical when the user wants to track an illicit discharge up a storm drain network to its source. Without knowledge of where 12-

inch storm drains are entering the 24-inch or greater storm drain system a source of discharge may be difficult to determine. For example, when sampling back up a storm drain network for the location of an illicit discharge or other point source, the 24-inch storm drains do not allow you to plan exactly where you will have to sample to determine the location of a discharge or source.

In summary, 24-inch storm drain information is sufficient for defining watershed boundaries in the context of sources, pathways and loading of containments entering the Bay from the urbanized watersheds. If small catchment areas are required or for tracking illicit discharges upstream to source, storm drain maps that incorporate drainage lines of less than 24 inches will be necessary. The difference in detail is visually obvious (Figure 7).

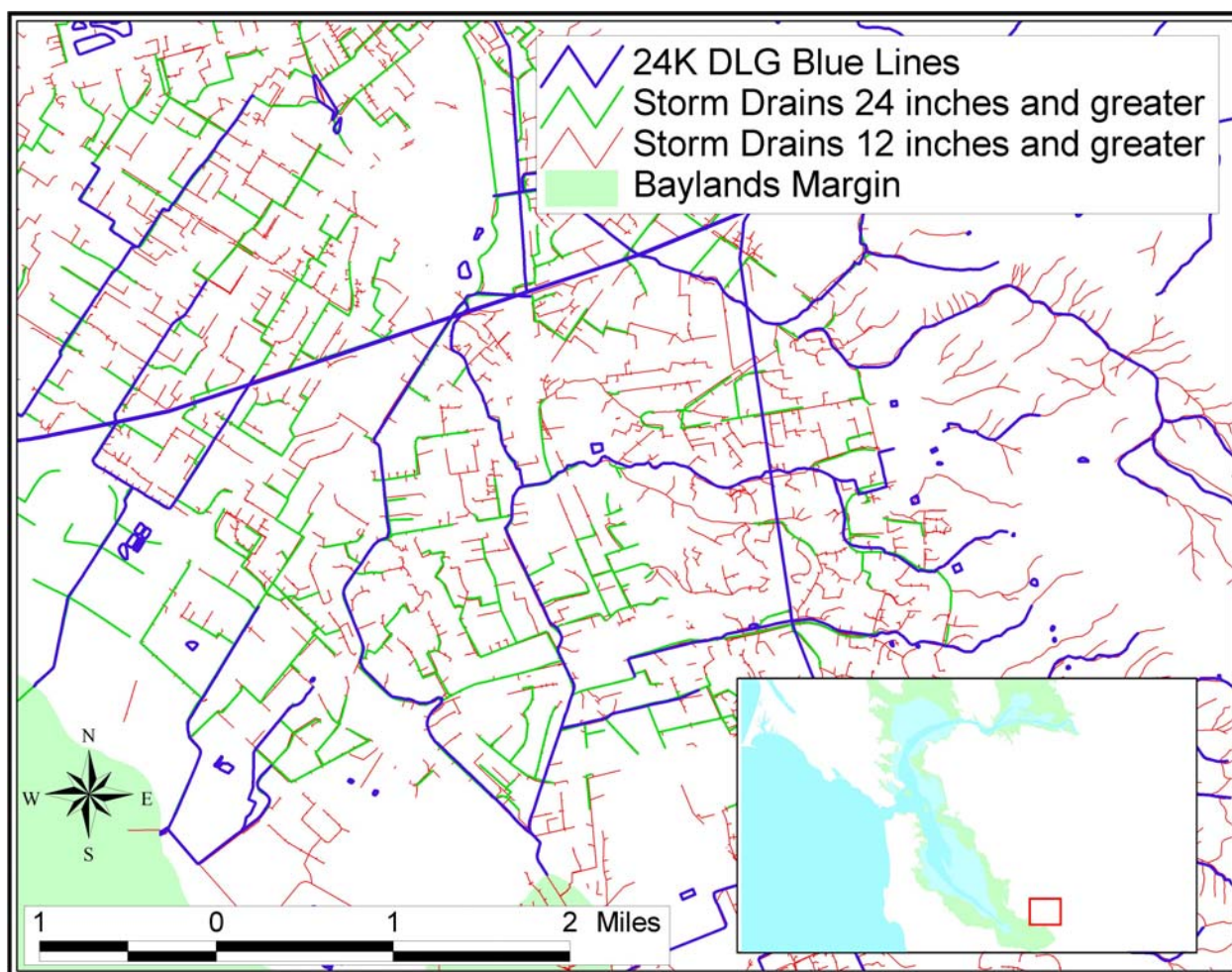


Figure 7. Comparison of 24 inch and 12 inch and greater storm drain layers

Methods of Storm Drain Routing

In order for storm drain information to be useful for modeling water flow and loads of contaminants, the network must be properly routed. Routing is required for tracking and modeling the source and destination of water flow. There are two primary methods of implementing routing: contiguous topology and downstream attributing.

Contiguous topology is when all the storm drain features connect to each other at their end points. You can select down stream features using these common end points. The problem is that very few storm drain coverages have complete topology. If they were not developed specifically as contiguous coverages, usually they contain storm drain features that are not connected to the rest of the network. These disconnected features usually result from the difficulty in translating engineering mapping styles into a GIS. In some cases a storm drain feature may intentionally not be connected to the rest of the network, for instance, if a series of pipes flow into a ditch that is then dispersed over an area to percolate down into the water table.

The ability to deal with disjunct features is one of the advantages of using attributing to implement routing. This method links each feature with the feature it flows to “downstream” using an attribute or a series of attributes. A coverage with contiguous topology, in effect, does the same; it just uses shared nodes as the linking attribute. This allows the user to select all features running to a single feature, or all the features down stream of a feature, using only attributes. The USEPAs Reach File 3 (RF3) system is an example of this type of routing.

The U.S. Environmental Protection Agency's (EPA) Reach Files are a series of hydrographic databases of the surface waters of the continental United States and Hawaii. The structure and content of the Reach File databases were created expressly to establish hydrologic ordering, to perform hydrologic navigation for modeling applications, and to provide a unique identifier for each surface water feature, i.e., reach codes. A key characteristic of the Reach Files is their attributes that define the connected stream network. These attributes provide connectivity regardless of the presence or absence of topologic continuity in the digital linework. Flow direction is inherent in the connectivity attributes. This attribute-level connectivity enables the Reach Files to provide hydrologic ordering of stream locations using reach codes (what is upstream and downstream of a given point in the stream network) as well as network navigation proceeding in either the upstream or downstream direction. A disadvantage of this system is that it can be labor intensive to attribute each individual feature with the appropriate attributes. Further information on the U.S. EPA Reach File Version 3.0 Alpha Release (RF3-Alpha) Technical Reference, 1994 and be viewed at www.epa.gov/owow/monitoring/rf/techref.html (cited April 2002).

How-To Manual

The pilot storm drain effort illustrated many of the steps required to create a usable storm drain layer for sources, pathways, and loadings as well as illicit discharge

purposes. The goal was to document these steps in such a format that was platform and software independent. There are five basic steps SFEI undertook to make the storm drain coverage usable.

Step 1: Determine if the layer is contiguous

The first thing the GIS technician must do with a storm drain layer is to determine whether or not it has contiguous topology (Figure 8). If all storm drain features within the layer are connected to each other, then the coverage has contiguous topology. Layers with contiguous topology are much easier to work with as much of the effort to attribute each feature with the down stream feature it flows to can be automated. However in most cases the coverages will not be contiguous, and will have a collection of unconnected, or disjunct, features.

Step 2: Determine if the layer has the appropriate flow direction

Next, the GIS technician must determine if the features in the layer, contiguous or otherwise, have been properly attributed or modified to indicate their flow direction (Figure 9). Different GIS packages handle flow direction in different ways, but the most common way is to have the nodes delineating the end of each feature each represent a "from" node and a "to" node. The storm drain layer metadata should indicate if features have proper flow direction, however it is always good to double check a few of the features just in case. If the layer does not have flow direction information, then manual correction of the features will be required. Manual correction should be completed even for disjunct portions of the network.

Step 3: Determine where disjunct features flow

Now that all the features are flowing in the right direction, the GIS technician must determine to where they flow (Figure 10). If there are no disjunct features, the GIS technician can move on to next step. However, most layers will have at least a few disjunct features. These features could be disjunct for a variety of reasons. In some cases there has been a simple error within the layer, and two features that were supposed to be connected never were. It is good to set a threshold at which the GIS technician will simply snap features together. A good rule of thumb is to use the accuracy of the source layer as your threshold. Some features may not be connected to the network because the analyst creating the layer could not determine to where the feature flowed. In this case, local expertise or field verification can provide the answer.

In some cases however, a storm drain system may simply flow onto an empty parcel and be dispersed over an area for percolation into the water table. These features are not part of the storm drain network, and should not be included for drainage area delineation. However, they are still important for illicit discharge purposes.

Step 4: Determine where upstream connections between drainage areas flow

In some cases, there is a feature that connects two drainage areas together high up within the watershed. These features could be a pipe that actually has a rise in the center, and water flows out both ends. In other cases it actually only flows one-way, and does not contribute to the other watershed. Still, on some occasions the pipe may contribute to both drainage areas. This process can be used to deal with upstream connections (Figure 11).

Step 5: Attribution of features

Once these steps to clean up the data have been completed, it is generally easy to write a routine to attribute the rest of the feature with the ID of the feature they flow to. In some cases it may still be necessary to do this attribution manually, but having the data edited and corrected greatly increases the speed in which you can accomplish this task.

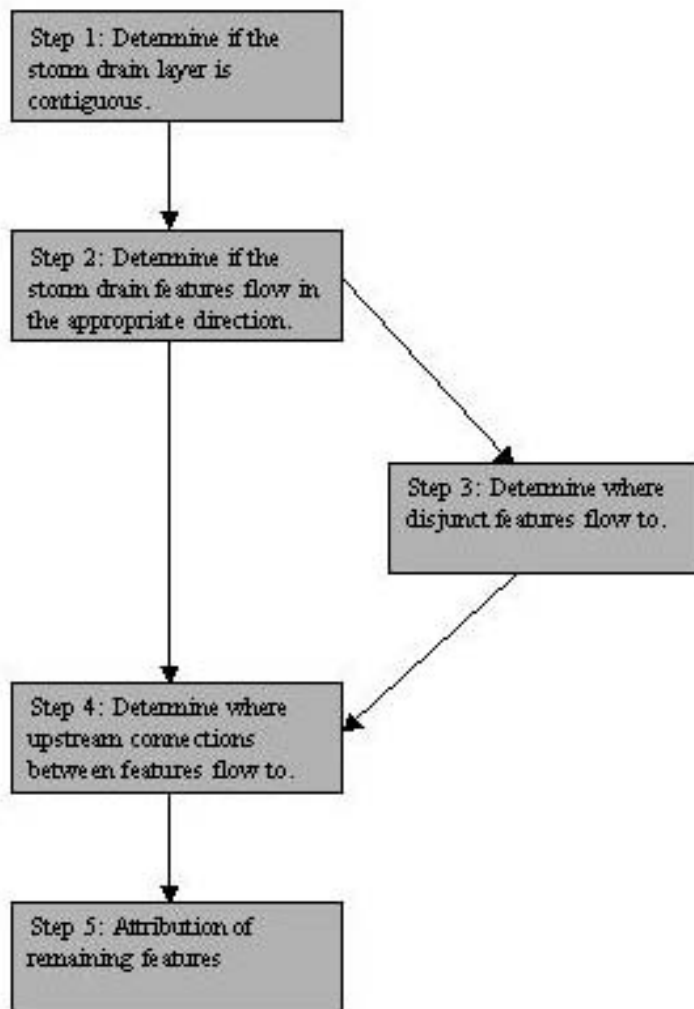


Figure 8. Steps to determine if the storm drain layer is contiguous.

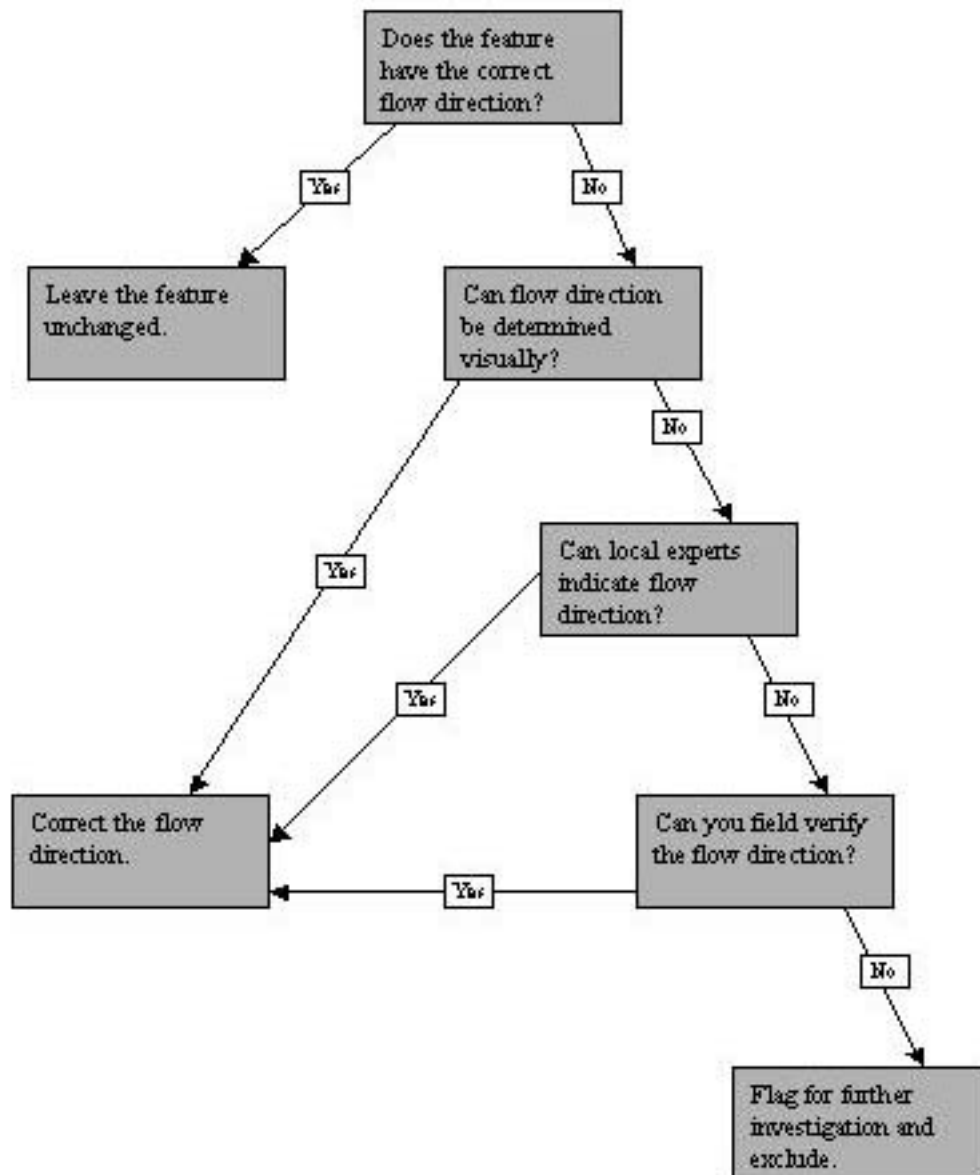


Figure 9. Steps to correct flow direction for a storm drain layer

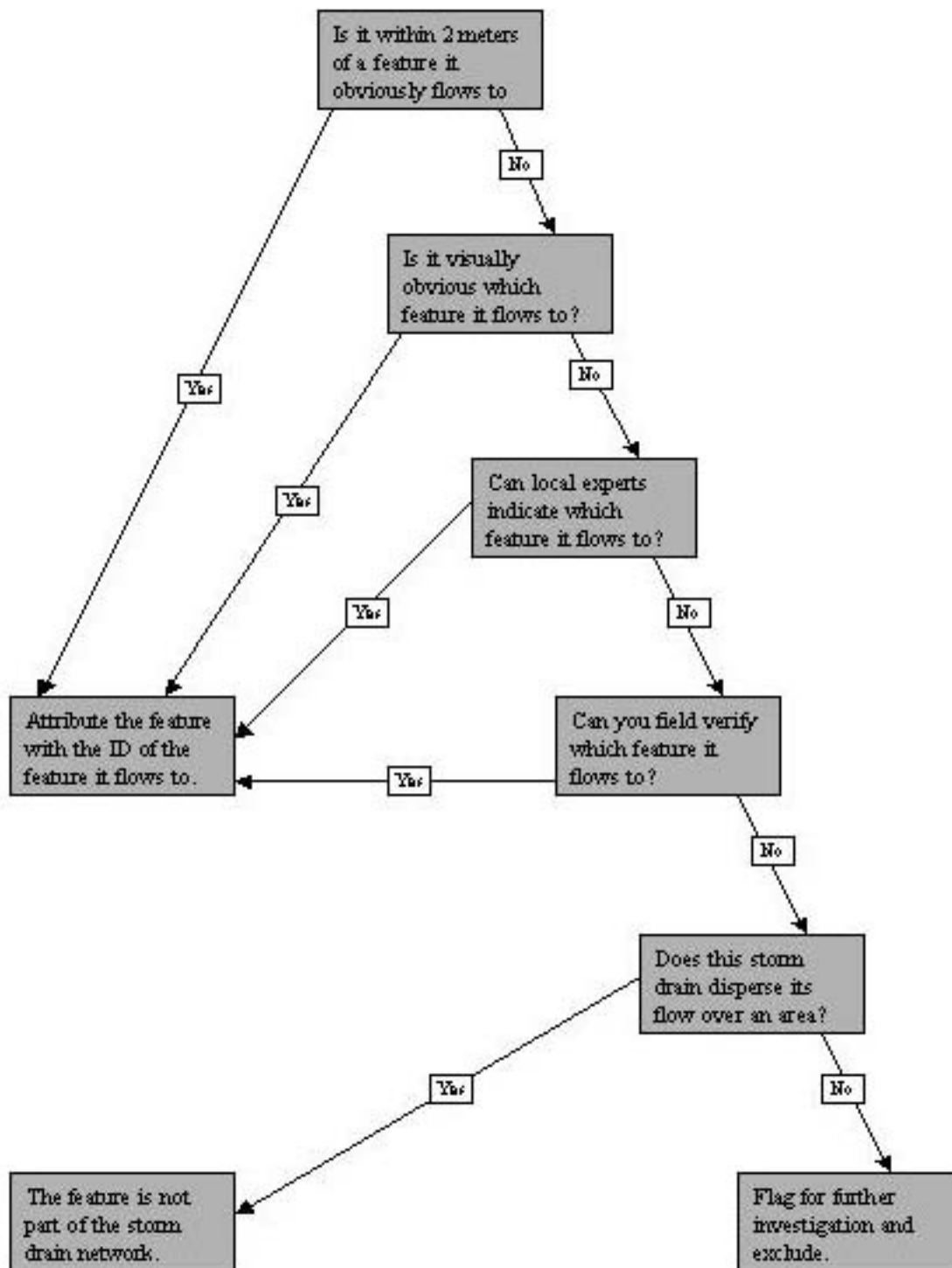


Figure 10. Steps to connect disjunct features.

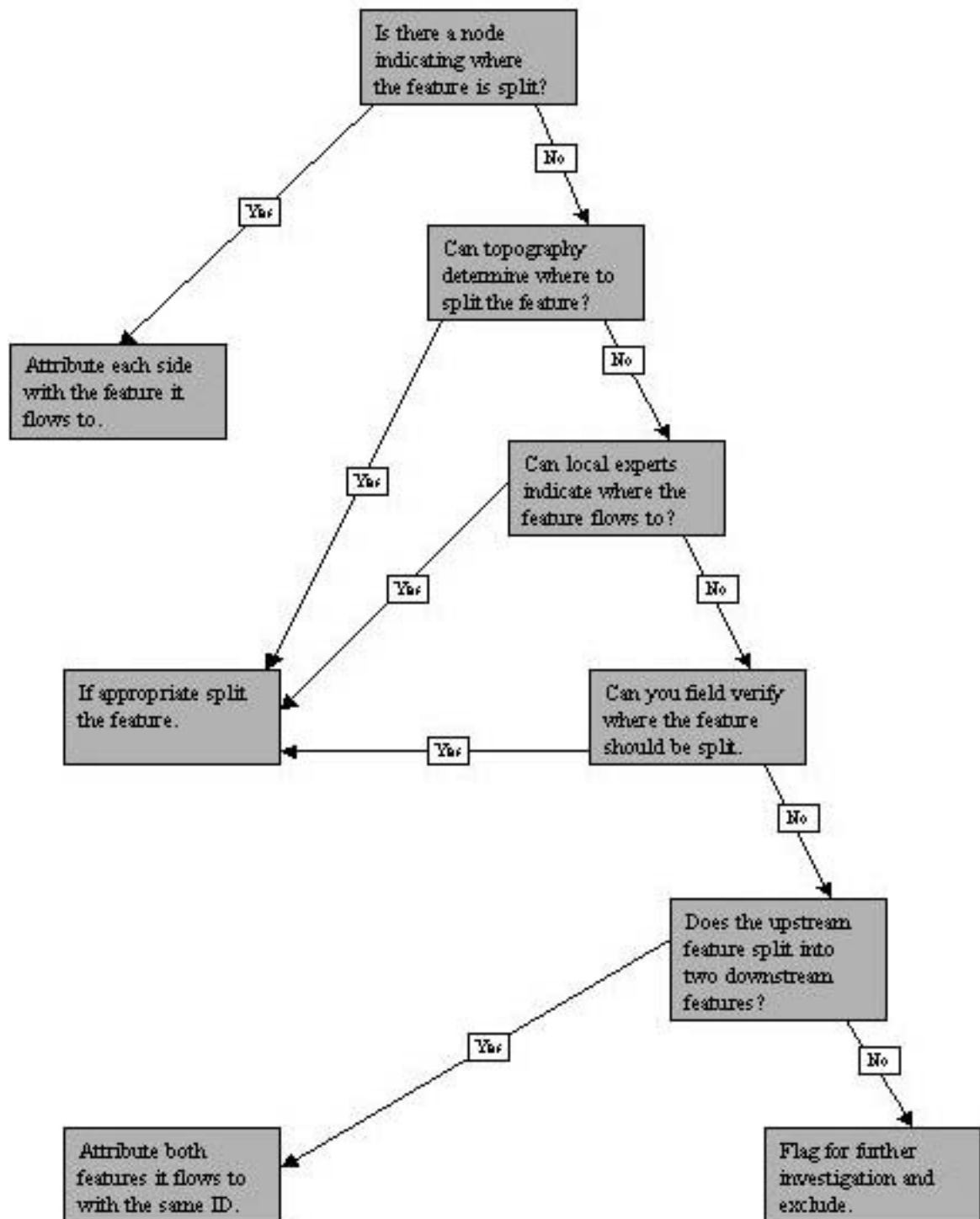


Figure 11. Steps to decide where best to split a storm drain connecting drainage areas.

Scenarios for Data Use

Characterization of Watersheds (Sources, Pathways and Loadings)

A user could take the synthesis product of urban (storm drain) and natural watersheds in the San Francisco Bay Area and use it to characterize watersheds over the whole Bay Area. Where sufficient data are present, or it is feasible to collect more data, information necessary to do a watershed analysis would be compiled. For example, the Sources, Pathways and Loadings Workgroup recently used the storm drain maps and watershed delineations to better determine the distributions of mercury (Figure 12) and PCBs and PAHs in the Bay Area. The Regional Board is using this kind of information to help prioritize watersheds for monitoring and management efforts.

Additional information could include spatial characteristics of the watershed such as total area, slope, aspect, distribution of various land use types, presence and area of mining efforts, and analysis of permeability. Additional information collected could be water flow gauging at various points along the stream, and other general information about water quality such as temperature.

Using this information, a simple characterization based upon known contaminant loading within the watershed could be performed. After characterizing multiple watersheds, a model could be developed to apply these characterizations to other watersheds based upon their spatial parameters and flow characteristics in order to predict their probable contaminant loading to the Bay.

Illicit Discharge Tracking

A regulator discovers that a toxic substance is present at an outflow point to the Bay. Using the storm drain coverage the regulator can determine what drainage area flows to that outflow point. They can then assess existing dischargers to see if this level of contamination is abnormal. Finding that the level is abnormal, the regulators can then develop a sampling scheme based on the existing storm drain information to assist in identifying from which storm drain within the drainage network the contamination actually came from. Upon visual inspection and/ or sampling up the storm drain network, it is discovered that the discharge is coming from a specific storm drainpipe. Using the hazard mapping effort the regulator looks at the various industrial areas along that storm drainpipe and identifies the potential problem area or source. A detailed survey of the storm drain pipes at probable location of input can then be conducted to identify the illicit discharger.

Conclusions

Mapping natural and modified drainages in Bay Area is a fundamental need for science and management support on a regional basis. Mapping is especially important in the context of improved research and management of sources, pathways, and loadings of

DRAFT Average concentrations of mercury in sediment (mg/kg).
Pilot RMP 1991-1992, RMP 1993-1999, BPTCP 1994-1997, BADALEMP 1994-1997, Stormdrain
Sediment Study 2000 (Gunther et al. 2001, KLI 2001), San Leandro Bay Study 1998 (Daum et
al. 2000), CALFED 1999.

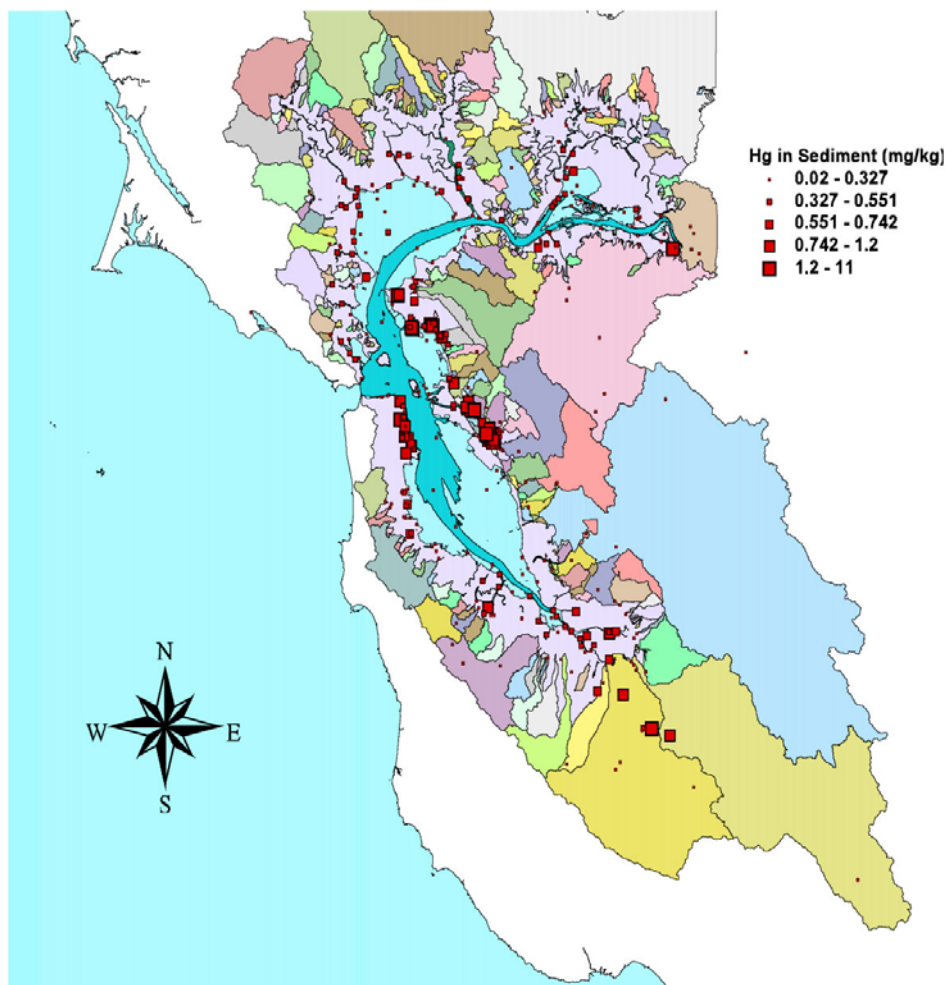


Figure 12. The distribution of mercury in bed sediments within storm drains and natural drainage lines of the Bay Area.

trace substances that enter the Bay from local tributaries. From that standpoint, perhaps the greatest success of the Project is in the synthesis of existing digital information for watershed boundary delineation. However the work products from this Project are best viewed as part of a continuum of technical and scientific development that contribute to the overall value of the series of work products that the SPLWG, the SFEI Watershed Program, and other city, county and consulting groups have developed over recent years.

The storm drain GIS inventory illustrated that there is not enough existing digital information to create a regional layer. However, many cities and counties are currently in the process of developing digitally mapped storm drain information. In order to achieve the goal of a regional storm drain data layer, partnerships and data sharing agreements with organizations developing storm drain layers need to be established. Advice and support needs to be provided to insure that layers being developed through these efforts are in a format that will be compatible with a regional effort.

Any effort to create a regional storm drain layer will have to be platform independent, and have a design flexible enough to deal with the variety of GIS mapping tools used in the Bay Area. Many GIS packages already have the means to implement routing as a pre-existing function. The problem is that these routing methods are not always compatible between platforms. Additionally, not all platforms store their line information in compatible topological formats. However, all GIS packages share some common abilities on the most basic level. They can map geographic features in real world coordinates, and they are capable of applying attributes to those features. Thus using an attribution-based storm drain routing method would have the greatest chance of being usable across platforms and also be able to use non-contiguous storm drain information.

In order to develop a comprehensive regional storm drain GIS, SFEI recommends that a method of storm drain routing, using attribution, be developed for the San Francisco Bay Area. This method should be developed in conjunction with other regional, state, and national hydrologic mapping efforts, as well as existing local storm drain mapping efforts. EPA's Reach File 3 hydrologic database effort might provide a good framework for designing a storm drain routing method. If a method could be developed that is compatible with the EPA's, then regional mapped storm drain information could be integrated with the USGS' 24K NHD effort. This would provide the users with a comprehensive map of hydrologic features, running from the non-urban less modified or natural drainage system through the modified storm drain and channel system to the Bay.

In order to develop a comprehensive regional storm drain GIS, SFEI recommends that a method of storm drain routing, using attribution, be developed for the San Francisco Bay Area. Additionally a method of mapping storm drains should be developed to assist organizations who have not yet begun their own mapping efforts. This method should be developed in conjunction with other regional, state, and national hydrologic mapping efforts, as well as existing local storm drain mapping efforts. Contra Costa County has developed an excellent method of storm drain mapping, that should be considered for use on a regional level. EPA's Reach File 3 hydrologic database effort might provide a good framework for designing a storm drain routing method. If a method could be developed that is compatible with the EPA's, then regionally mapped storm drain information could be integrated with the USGS' 24K NHD effort. This would provide the users with a comprehensive map of hydrologic features, running from the non-urban less modified or natural drainage system through the modified storm drain and channel system to the Bay.

The primary limitation of this effort is the time scale of implementation. Some organizations may be unwilling or uninterested in working to create a regional storm drain GIS. However, the greatest factor is a lack of money, people and resources. Organizations may not have the available resources to implement GIS anything but the most basic storm drain mapping effort. Organizations may have already invested a great deal of time and effort in a storm drain mapping effort in a CAD format that is perfectly suited to local applications, maintenance and planning, and therefore may not be willing (for a variety of reasons) to assist in developing cross walks to a regional GIS system. This would necessitate an alternative data steward to develop a means to translate, incorporate, and maintain the information from those organizations.

The majority of organizations contacted in the storm drain GIS inventory expressed interest in being involved in such an effort. Even with the full cooperation of cities and counties developing new information, the ability to move towards a regional GIS would be dictated by their timetables. Relying on the completion of this effort to fulfill the needs of Sources, Pathways and Loadings analysis may not be feasible. However, the fact that many organizations are undertaking an effort to map storm drains currently, or within the near future, provides us with an opportunity to slowly compile a regional map over time. Therefore it seems that the main factor that is inhibiting the development of a regional GIS of storm drains is funding.

There is an alternative method of acquiring accurate watershed delineations for Sources, Pathways, and Loadings analysis. Rather than compile storm drain information, and then go through the effort of generating and verifying urban watersheds, it may prove more useful and timely to create a synthesis product of existing urban watershed mapping efforts. Since accurate mapping of urban watersheds is more dependant on effective ground verification than a properly routed storm drain GIS, it is possible to use even hard copy maps of storm drains to generate watershed boundaries.

Many cities and counties have made efforts to generate urban watershed delineations already, and it is not uncommon for organizations to be developing a storm drain GIS and urban watershed boundaries simultaneously. SFEI has taken a first step towards creating a regional watershed synthesis product, and recommends that this effort be continued. The result would be a coverage comprised of varying data quality, precision, and update frequency. As long as feature specific metadata are maintained, the benefits of such a coverage would outweigh the flaws and inconsistency between methods and accuracy of watershed delineation.

Since one of the prerequisites for meeting the needs of illicit discharge trackers is a properly routed storm drain GIS, there is no means (or the need) to meet this level of product on a regional basis in the short term. Applications could be developed on a site-specific basis, and built to the requirements of the illicit discharge staff of a county or city. However, these systems would not be integrated with a regional effort. Even after the storm drain data have been collected and compiled on a regional level, the existing diversity of software applications and platforms still represents a challenge to delivering

a usable product. The tool would have to be developed as a web application to allow use from any platform. Additionally the needs analysis for the tool would have to be extensive, to insure that it met the majority of the needs of involved parties. Additionally, results and determinations from the tool would have to be easily exportable to a variety of formats.

Recommendations for Future Efforts

1. Institutional support needs to be enhanced and funds need to be found to assist Oakland Museum and William Lettis & Associates to continue their effort to compile and field truth drainage systems (including 24 in storm drains) around the margins of the Bay.
2. Research effort on methods on integrating storm drain data with streams data
 - a. Literature Review
An effort to review and evaluate all existing literature regarding storm drain mapping, and storm drain and stream network integration should be conducted. A summary document providing detailed descriptions of other methods and means of both the organization and integration of storm drain information should be produced.
 - b. Coordinate with EPA/ USGS/ ESRI
Efforts to integrate our regional storm drain effort with existing regional hydrologic mapping efforts should be undertaken. Specifically our method should be compatible with EPA's RF3 stream database system, and USGS' NHD effort. ESRI is continuing its development of data models for hydrologic data storage and analysis. Any method should take into account these new emerging standards and tools.
 - c. Develop procedural document
Once the various methods have been reviewed for feasibility, and compatibility with existing efforts, one will be selected. This procedure must be documented thoroughly.
 - d. Implement changes to NHD/RF3
In order to implement the above method it may be required to make changes or additions to RF3 or NHD.
3. Urban and natural watershed synthesis
 - a. Collect watershed and urban drainage information where available
 - b. Convert data into the appropriate format and projection
 - c. Develop metadata where not readily available for each source
 - d. Integrate data with regional watershed coverage
 - e. Develop partnership for development and maintenance of coverage
4. Watershed attribution with statistical information
 - a. Determine land use characteristics by contaminant
 - b. Develop program to generate statistics by contaminant
 - c. Develop program to generate statistics for general land use

- d. Develop program to generate statistics for slope
 - e. Develop program to generate statistics for aspect
 - f. Develop program to generate statistics for wetlands/bay lands
5. Storm Drain Application Requirement Study
6. RF3/NHD storm drain integration pilot
- a. Select pilot Catalogue Unit
 - b. Collection of storm drain data
 - c. Combine storm drain data into a single coverage
 - d. Attribute storm drain data
 - e. Integration of storm drain data into NHD
 - f. Assignment of new reach-codes and other attributes
7. Storm Drain Application Development
8. RF3/NHD storm drain integration project
(same as 5 but with new CUs)

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Interagency California Watershed Mapping Committee, 1998. The California Watershed Map (CALWATER version 2.0) is a set of standardized watershed boundaries meeting standardized delineation criteria. Ordering Instructions: Richard Neal, California Department of Water Resources, 1416 Ninth Street, Sacramento, California, 95814; Telephone::916-653-7574; Fax::916-653-6077
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