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Development of an Information Data Base for Watershed Monitoring

Landsat multispectral scanner data, Defense Mapping Agency digital terrain data, conventional maps, and ground data were integrated to create a comprehensive information data base for Lake Tahoe and its environs.

ABSTRACT: *Lake Tahoe is one of very few natural lakes in the United States which has remained relatively undamaged by the encroaching developments of man. The management of Tahoe's water quality has become a subject of intensive study in recent years in an effort to define and limit the effects of nonpoint source pollutants that are input from the contributing drainage basins.*

As an aid to the water quality management effort, the Image Processing Laboratory at Caltech's Jet Propulsion Laboratory has integrated Landsat multispectral scanner data, Defense Mapping Agency digital terrain data, conventional maps, and ground data to create a comprehensive information data base for Lake Tahoe and its environs. The project used the resources of the JPL-developed Image Based Information System (IBIS) programs to augment data gathered by the U.S. Forest Service for the Tahoe Regional Planning Agency.

The IBIS data base method allowed cross correlation of Landsat imagery and topographic data with a variety of environmental data relating to such parameters as surface runoff, drainage basin acreage, and terrain configuration. Parameters were evaluated and compared for each drainage basin defined by the Tahoe Regional Planning Agency (1977).

The methods used to construct and update the information data base will be described and evaluated. In addition, the utility of including Landsat imagery will be discussed.

THE LAKE TAHOE BASIN

THE GROWTH of human society impacts the environment in many ways. One region facing the problems associated with this growth is the Lake Tahoe Basin. The Tahoe Basin occupies over 500 square miles (1295 km^2) situated in a graben straddling the boundary between California and Nevada. Lake Tahoe contains 126 million acre feet (155.4 km^3) of water in a 190 square mile (492.1 km^2) surface area receiving inflow from 63 tributaries with only one outlet at the Truckee River. The Tahoe Basin has traditionally attracted recreational activity due to its clear deep water and pine-forested shorelands coupled with its proximity to major metropolitan areas in Northern California. Since the 1950's the basin has experienced escalating demands for land development at the expense of the natural watershed. Discharge of sediments to the

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lake has greatly increased due to accelerated human interference, and alterations to the natural drainage patterns are evident in some areas.

The problems which the Lake Tahoe Basin is presently confronting are certainly not unique to this area. These consequences of man's alteration of the natural environment are symptomatic of the pressures which can be brought to bear by the activities of an increasingly mobile populace.

The Jet Propulsion Laboratory's (JPL) Image Processing Laboratory (IPL) has for five years been concerned with developing techniques which can aid water quality management programs charged with the task of monitoring and assessment of the trophic status of these troubled lakes. In the past, the major emphasis has been placed upon assessing the viability of Landsat as a monitoring device and the development of a useable system for water quality management personnel (Blackwell and Boland, 1979; Smith and Addington, 1978). As a result, water quality in terms of the water body per se has been closely studied without major emphasis given to the contributing factors, such as nonpoint source pollutants from the surrounding land mass. In order to investigate the utility of a comprehensive system which takes into account the causes as well as the effects of lake eutrophication, the IPL has attempted to construct an integrated and workable data base, composed of currently available data sources, for the Lake Tahoe region. The purpose of such a data base is to integrate water quality related data from various sources into a comprehensive system which is capable of combining and cross-referencing such diverse elements as conventional maps, Landsat imagery, and tabular data obtained via in-situ methods. Such a system provides the environmental planner with the ability to visualize the integration of disparate data elements which formerly would have to be examined manually. The analyst can also combine data so as to generate new tabulations based upon cross-referencing of the various elements.

THE IMAGE BASED INFORMATION SYSTEM

To achieve the goal of a workable data base, IPL has relied upon the resources of its own information system, IBIS, which was designed specifically for this type of application. IBIS is a system composed of general purpose and specialized computer programs which can be grouped into logical steps to build an information data base (Bryant and Zobrist, 1978; Zobrist and Bryant, 1979). Functionally, IBIS represents a selection of programs which operate under the Image Processing Laboratory's VICAR Image Processing System (*V*ideo *I*nformation *C*ommunication and *R*etrieval). The IBIS system is raster (image) based but allows integration of graphical and tabular data types as well. Image data sets can originate from a variety of sources such as Landsat or other imaging systems. Graphical data, such as from conventional maps, are electronically digitized and transformed into image format for integration into the system. Tabular data are linked to the system via an interface between the image data planes and entered through table-structured input which is keyed to a georeference plane (Yagi *et al.*, 1978). The georeference plane is a map-based graphical representation of areas of interest, such as drainage basins. Data base storage, retrieval, and analysis operations are all performed using the VICAR digital image processing routines. Each image entered into the data base is geometrically corrected and registered to a planimetric base image creating a system of data planes, as illustrated in Figure 1. Each image plane is referenced to one or more georeference planes to which all tabular data are also keyed. The user is thus able to manipulate data from several sources which, despite their original disparity, are all referenced to a common base, usually geographic in origin.

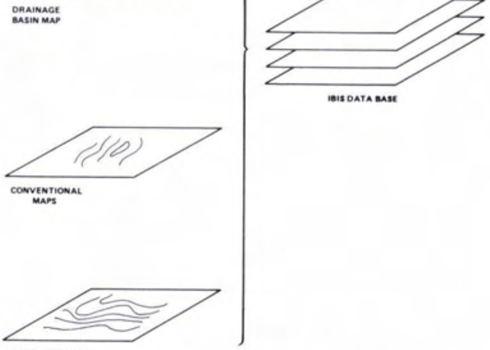


FIG. 1. Conceptual diagram depicting data planes in registration forming the IBIS data base.

CONSTRUCTION OF THE LAKE TAHOE BASIN DATA BASE

IPL chose to construct the Lake Tahoe Basin data base from data sources which were readily available and familiar to its analysts. Landsat imagery, which has formed the basis for the majority of IPL's water quality assessment efforts, was chosen as the planimetric base to which all other data would be registered. A subsection of a Landsat 2 scene from 27 August 1976 was extracted and transformed into a Lambert Conformal Conic projection to serve as the planimetric base. To this scene two other Landsat scenes were registered, one from Landsat 2, 21 July 1978, and one from Landsat 3, 30 July 1978. Registration was achieved through the aid of a piece-wise surface fitting algorithm. The surface transformation was defined through a series of tiepoints selected during the use of an interactive spatial pattern recognition routine in which the analyst selected common geographical features (Ruiz *et al.,* 1977; Davis and Friedman, 1979). After all images were registered, color reconstruction was also performed on each scene using a color enhancement technique which approximates a Gaussian distribution using the principal components of each Landsat image separately (Madura and Soha, 1978). This type of enhancement was designed to attempt even distribution for all regions within an image to avoid the saturating effects of conventional linear enhancements.

Terrain data produced by the Defense Mapping Agency (DMA) were next integrated into the data base. Digital terrain tapes were acquired for the Lake Tahoe region from the National Cartographic Information Center. The tapes were prepared from U.S. Geological Survey (USGS) 1:25,000 scale topographic quadrangle map series. Map contour lines falling within a one degree block of latitude and longitude were digitized and a matrix of elevations generated with one elevation for every 0.01 inch on the map (200 feet/60.96 metres on the ground). The terrain data were reformatted for use in IPL's VICAR operating system. In reformatting, halfword integer elevation values were converted to single byte integers and scaled to the terrain variation within the area (Strahler *et al.,* 1979).

After reformatting, the terrain data sets were rotated 90 degrees counterclockwise to orient the north at the top of the images. This compensated for data format as produced by the National Cartographic Institute. For the Lake Tahoe Basin, four separate terrain quadrangles were required to construct a complete image comprising the Tahoe Basin area. This necessitated the mosaicking of the four quadrangles before final registration to the data base. Figure 2 reproduces the four digital terrain quadrangles required to completely encompass the Lake Tahoe Basin and the final mosaic image. The relief-like effect portrayed in the images were produced by digitally shading between contour intervals.

Registration of the terrain mosaic with the Landsat planimetric base was achieved through the application of a resampling algorithm which applied a two-dimensional correction grid derived from selected control points (Yagi *et al.,* 1978; Ruiz *et al.,* 1977). Tiepoint selection was achieved interactively relating surface features through comparison of the Landsat planimetric base image and a relief-like version of the terrain image.

Graphical data for the Lake Tahoe Basin data base were acquired from conventional maps produced for the Tahoe Regional Planning Agency by the U.S. Forest Service. These maps presented hydrologic and climatologic data pertaining to the Lake Tahoe Basin. Before integration into the IBIS data base, graphical data must be transformed into image format. This was achieved by first digitizing the graphical data onto magnetic tape. Next, a least-squares affine transformation was applied which created a general surface fit. Corresponding line and sample coordinates, in terms of the Landsat planimetric base, were calculated from latitude and longitude coordinates taken from the graphical map data for geographical features common to both data sets. Registration was once again achieved through the selection of control points which linked geographical features from the graphical data file and the planimetric data base. In Figure 3, the transformation of a conventional map to a graphical data plane is illustrated. Step A represents the digitizing procedure in which the drainage basin map is converted to graphical image format.

A georeference image plane, which provided an interface between all data planes for the Lake Tahoe Basin data base, was created from the drainage basin map provided by the Tahoe Regional Planning Agency. As seen in Figure 3, this map identified the location and outlined the boundaries for the 63 drainage basins identified as providing watershed inflow to Lake Tahoe. The map was digitized and subsequently registered to the planimetric base. Each separate drainage basin was then assigned a

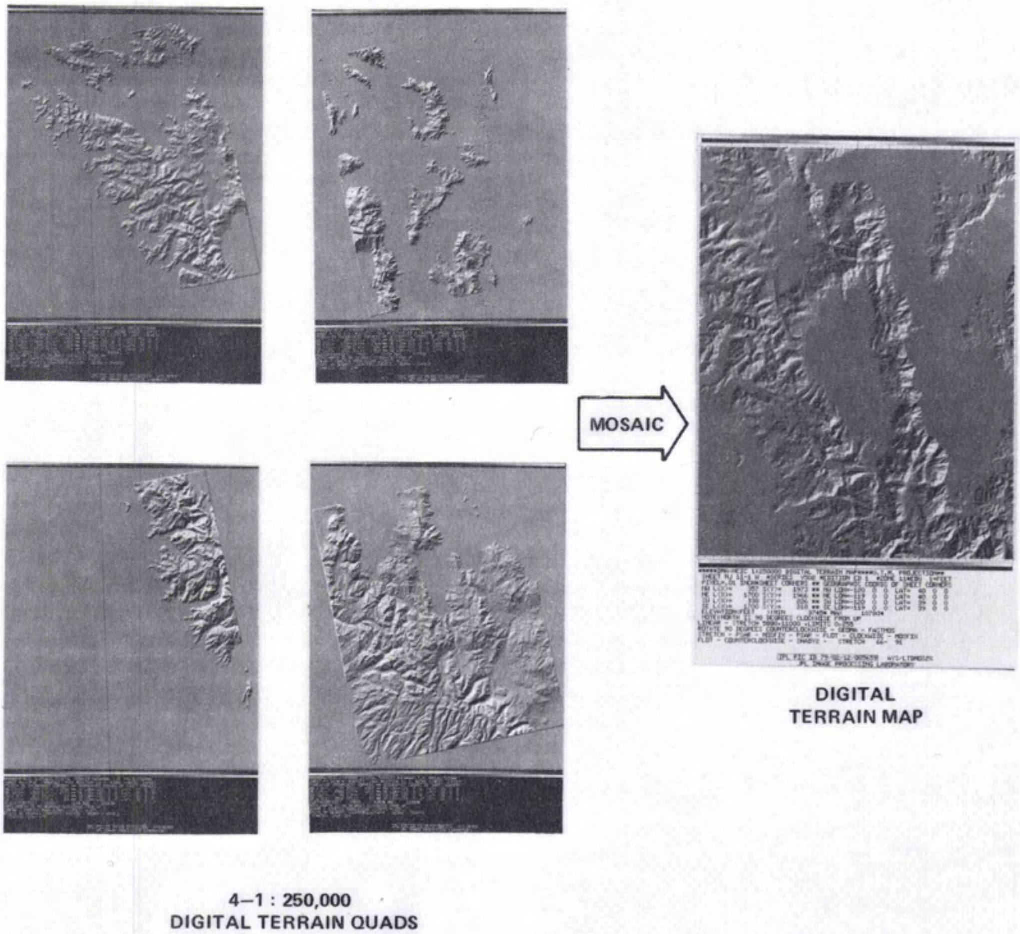


FIG. 2. Four digital terrain quadrangles mosaicked to produce a terrain map which contains the Lake Tahoe Basin.

unique data number for all picture elements comprising that basin. Step B, in Figure 3, represents the process of encoding each drainage basin, a procedure known as "painting". The final product, the georeference plane, is reproduced at the right in Figure 3. All tabular data corresponding to the drainage basins were then entered into the data base by referencing the unique number assigned to each basin. The georeference plane is an integral element within the data base, for it is through this plane that all tabular and most image data are interfaced. Figure 4 is a conceptualization of the georeference plane for the Tahoe region. The magnified portion of the figure indicates the coded picture elements which comprise each basin. In a most basic application, the picture elements for each basin are summed and transferred to an interface file in which the sums are stored according to basin code number. This interface file can be accessed at a later date to produce statistical output such as acreage estimates.

The Lake Tahoe Basin data base cannot be considered to be complete at this time. The elements presently contained within it are only a small sampling of data which can be integrated into such a system. The IBIS data base as IPL has designed it implies a dynamic system which can be constantly updated to reflect the most recent environmental and resource data available to the analyst. For instance, as new multispectral scanner data or other georeferenced information becomes available, it can be integrated into the system to replace or augment current imagery and related data.

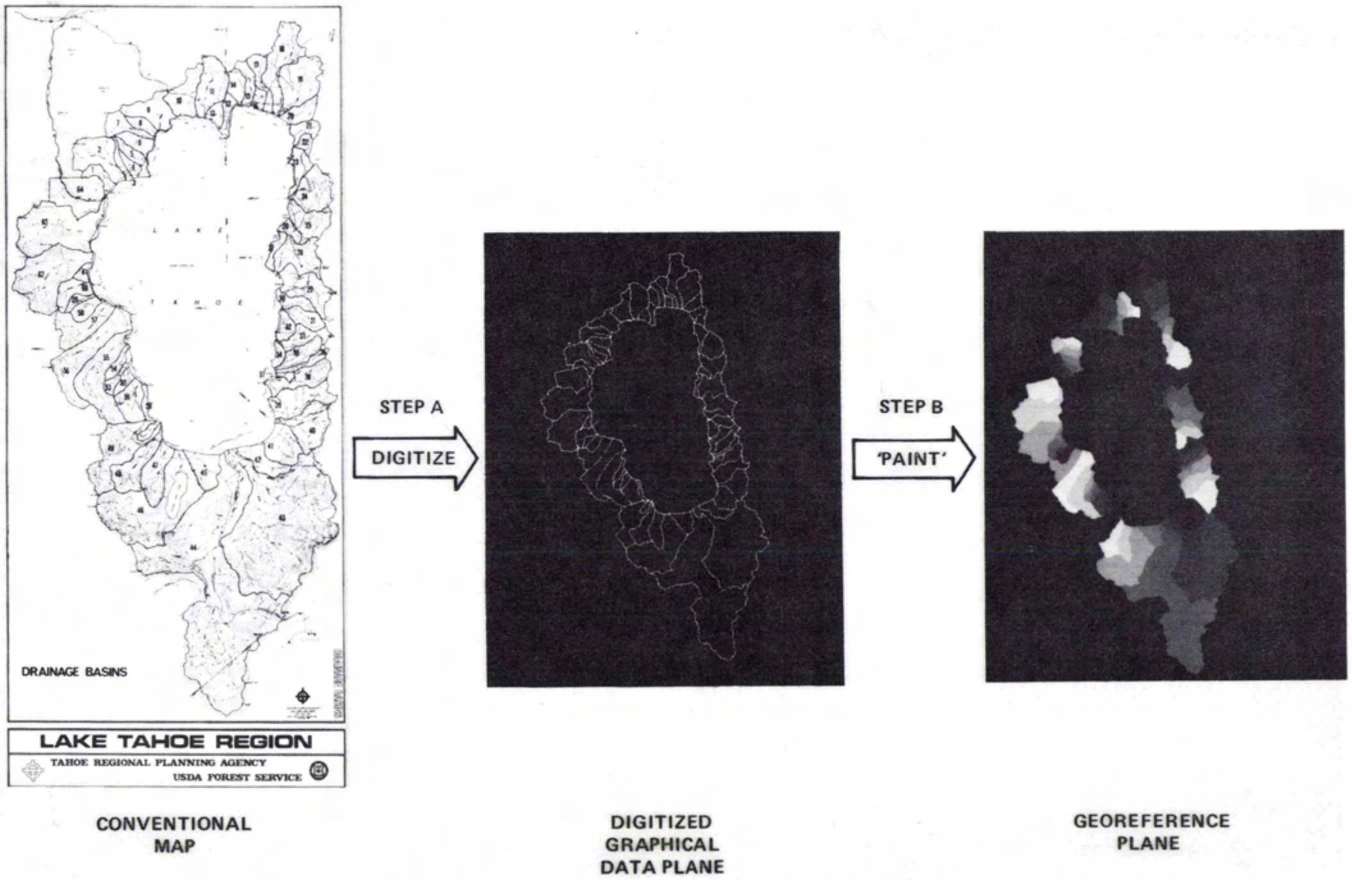
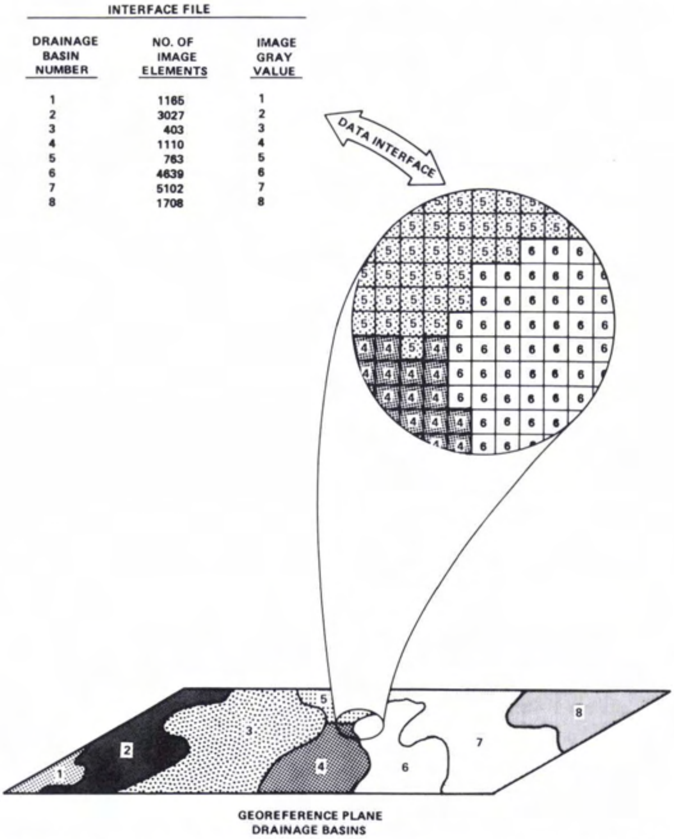


Fig. 3. Transformation of a conventional map to a graphical data plane and georeference plane.



INTERFACE FILE

DRAINAGE BASIN NUMBER	NO. OF IMAGE ELEMENTS	IMAGE GRAY VALUE
1	1165	1
2	3027	2
3	403	3
4	1110	4
5	763	5
6	4639	6
7	5102	7
8	1708	8

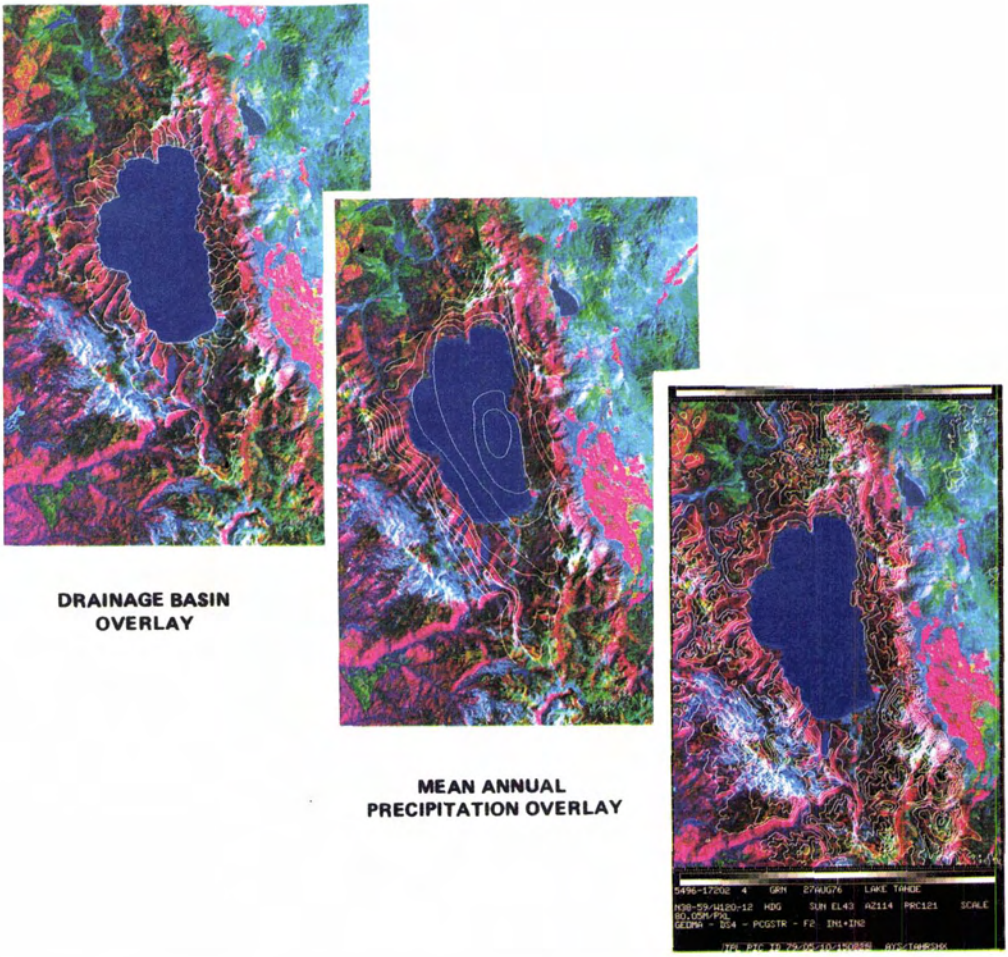
Fig. 4. Conceptual drawing of the georeference plane and tabular interface file (after S. Z. Friedman, 1978).

Application of the IBIS Concept to the Lake Tahoe Basin

Manipulation and integration of data planes comprising the data base are achieved through the implementation of VICAR and IBIS programs developed at JPL. Plate 1 illustrates standard hardcopy outputs produced from data plane integration. The Landsat scene for 27 August 1976 has been summed with three separate graphical data planes to produce overlay images. This type of imagery surpasses what is otherwise available to the analyst in the form of side-by-side comparison of conventional map versus Landsat image. The image to the left in Plate 1 defines the drainage basin boundaries. The middle image was produced by overlaying mean annual precipitation isohyets. The digital terrain mosaic was transformed to display 600-foot contour intervals and was overlayed on Landsat to produce the image to the right. Each of these images represents a visual tool, which provides the analyst with increased perspective, allowing more exact analysis of diverse data. In future applications the mean annual precipitation isohyets will be converted to a continuous surface image. This process is similar to the conversion of USGS topographic maps to terrain relief images as depicted in Figure 2. The precipitation image will then be cross-tabulated with individual drainage basins to produce estimates of runoff coefficients.

Implementation of the georeference plane provides the opportunity for the analyst to examine more closely the unique characteristics of each drainage basin as revealed by the Landsat sensors. As depicted in Plate 2, each drainage basin mapped by the Forest Service can be extracted from the Landsat imagery and displayed separately. If a multispectral classification is then performed on the Landsat data, information can be similarly reproduced in a basin-by-basin format, thus permitting tabulations of land-cover type. The georeference plane can also be interfaced with tabular files to produce a statistical output such as that reproduced in Figure 5. In this table, the area of each uniquely coded drainage basin comprising the georeference plane was determined by summing picture elements and converting the sum to total acres. These data were then cross-referenced to tabular files which contain acreage estimates produced by the Tahoe Regional Planning Agency. All estimates were then ranked and output in the form of a computer listing, which provided a comparison of Landsat versus conventionally acquired acreage estimates.

The inclusion of digital terrain data provided an opportunity to integrate an important element of ancillary, ground-based information with remote sensing data. The Defense Mapping Agency developed these data by interpolating existing USGS 1:250,000 scale topographic maps to produce ultrafine mesh digitized latitude, longitude, and elevation contour data. As described earlier, four DMA quadrangles were digitally mosaicked to form a unified, continuous surface elevation image. This image was then geometrically registered with the Landsat imagery to permit future cross-tabulations of elevation information with other information data planes within the data base. In an effort to quantify and process the digital terrain data, the elevation image was processed with VICAR software to produce a component representing slope magnitude. To develop this component it was necessary to compute the vector cross product between the horizontal (east-west) image elements and the vertical (north-south) picture ele-

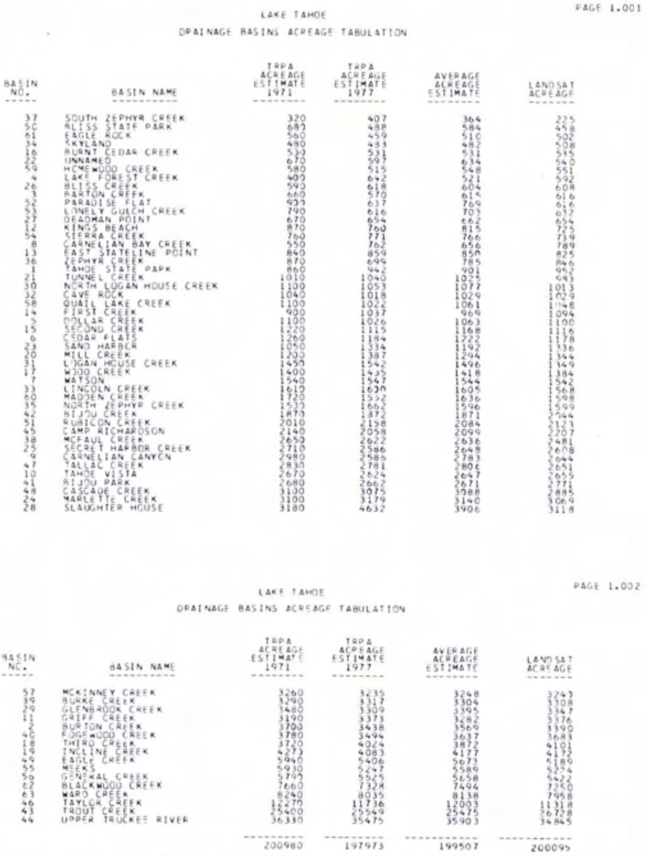


DRAINAGE BASIN OVERLAY

MEAN ANNUAL PRECIPITATION OVERLAY

DIGITAL TERRAIN CONTOURS (600′ INTERVAL) OVERLAY

PLATE 1. Integration of data planes produces overlay images creating new visual and analytical tools which combine data from various sources.



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                                LAKE TAHOE                                    PAGE 1.001

                      DRAINAGE BASINS ACREAGE TABULATION

                                          TRPA        TRPA
                                        ACREAGE     ACREAGE      AVERAGE
BASIN                                   ESTIMATE    ESTIMATE     ACREAGE       LANDSAT
 NO.         BASIN NAME                   1971        1977       ESTIMATE      ACREAGE
-----        ----------                 --------    --------     --------      -------

  37     SOUTH ZEPHYR CREEK                 320         407          364           225
  50     BLISS STATE PARK                   680         488          584           458
  61     EAGLE ROCK                         560         459          510           502
  34     SKYLAND                            480         483          482           508
  16     BURNT CEDAR CREEK                  530         531          531           535
  22     UNNAMED                            670         597          634           540
  59     HOMEWOOD CREEK                     580         515          548           551
   4     LAKE FOREST CREEK                  400         642          521           592
  26     BLISS CREEK                        590         618          604           608
   3     BARTON CREEK                       660         570          615           616
  52     PARADISE FLAT                      900         637          769           616
  53     LONELY GULCH CREEK                 790         616          703           632
  27     DEADMAN POINT                      670         654          662           654
  12     KINGS BEACH                        870         760          815           725
  54     SIERRA CREEK                       760         771          766           739
   8     CARNELIAN BAY CREEK                550         762          656           789
  13     EAST STATELINE POINT               840         859          850           825
  36     ZEPHYR CREEK                       870         699          785           846
   1     TAHOE STATE PARK                   860         942          901           952
  21     TUNNEL CREEK                      1010        1040         1025           993
  30     NORTH LOGAN HOUSE CREEK           1100        1053         1077          1013
  32     CAVE ROCK                         1040        1018         1029          1029
  58     QUAIL LAKE CREEK                  1100        1022         1061          1048
  14     FIRST CREEK                        900        1037          969          1094
   5     DOLLAR CREEK                      1100        1026         1063          1100
  15     SECOND CREEK                      1220        1115         1168          1116
   6     CEDAR FLATS                       1260        1184         1222          1178
  23     SAND HARBOR                       1050        1334         1192          1336
  20     MILL CREEK                        1200        1387         1294          1344
  31     LOGAN HOUSE CREEK                 1450        1542         1496          1349
  17     WOOD CREEK                        1400        1435         1418          1384
   7     WATSON                            1540        1547         1544          1542
  33     LINCOLN CREEK                     1610        1630         1605          1568
  60     MADDEN CREEK                      1720        1552         1636          1598
  35     NORTH ZEPHYR CREEK                1530        1662         1596          1599
  42     BIJOU CREEK                       1870        1872         1871          2044
  51     RUBICON CREEK                     2010        2158         2084          2123
  45     CAMP RICHARDSON                   2140        2058         2099          2207
  38     MCFAUL CREEK                      2650        2622         2636          2481
  25     SECRET HARBOR CREEK               2710        2586         2648          2608
   9     CARNELIAN CANYON                  2980        2586         2783          2644
  47     TALLAC CREEK                      2830        2781         2806          2651
  10     TAHOE VISTA                       2670        2624         2647          2655
  41     BIJOU PARK                        2680        2662         2671          2771
  48     CASCADE CREEK                     3100        3075         3088          2885
  24     MARLETTE CREEK                    3100        3179         3140          3069
  28     SLAUGHTER HOUSE                   3180        4632         3906          3118


                                LAKE TAHOE                                    PAGE 1.002

                      DRAINAGE BASINS ACREAGE TABULATION

                                          TRPA        TRPA
                                        ACREAGE     ACREAGE      AVERAGE
BASIN                                   ESTIMATE    ESTIMATE     ACREAGE       LANDSAT
 NO.         BASIN NAME                   1971        1977       ESTIMATE      ACREAGE
-----        ----------                 --------    --------     --------      -------

  57     MCKINNEY CREEK                    3260        3235         3248          3243
  39     BURKE CREEK                       3290        3317         3304          3308
  29     GLENBROOK CREEK                   3480        3309         3395          3347
  11     GRIFF CREEK                       3190        3373         3282          3376
   2     BURTON CREEK                      3700        3438         3569          3390
  40     EDGEWOOD CREEK                    3780        3494         3637          3683
  18     THIRD CREEK                       3720        4024         3872          4101
  19     INCLINE CREEK                     4270        4083         4177          4172
  49     EAGLE CREEK                       5940        5406         5673          5189
  55     MEEKS                             5930        5247         5589          5274
  56     GENERAL CREEK                     5790        5525         5658          5422
  62     BLACKWOOD CREEK                   7660        7328         7494          7250
  63     WARD CREEK                        8240        8035         8138          7958
  46     TAYLOR CREEK                     12270       11736        12003         11318
  43     TROUT CREEK                      25400       25549        25475         26728
  44     UPPER TRUCKEE RIVER              36330       35475        35903         34845

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                                         200980      197973       199507        200095
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FIG. 5. Keying of the georeference plane with Landsat data and U.S. Forest Service data generated this tabular report.

ments. This vector product then provided an estimate of the slope between adjacent east-west and north-south elevation image elements. The outputs of this process were then coded to reflect slopes between 0° (no slope) and 90° (vertical slope). The angle in degrees was further coded for image output by rescaling 0° to be equal to 0 digital number (DN) or black and 90° to be equal to 255 DN or white. Figure 6 illustrates an application of these concepts. First, the slope magnitude was cross-tabulated with the drainage basin georeference plane. Each slope magnitude image element associated with the individual drainage basins was then extracted. Further cross-tabulation permitted the computation of a mean slope estimate by averaging the slope magnitude image elements for each drainage basin.

Figure 7 reproduces an IBIS table generated from the digital terrain imagery which lists azimuth and slope for each drainage basin. Eventually, it is hoped to develop a model for drainage basin terrain based on digital imagery. At present, however, difficulties have been encountered with discrepancies between individual DMA map quadrangles, especially along map edges, which have precluded the development of accurate models. Other types of digital terrain imagery are being investigated with the hope of integrating more reliable data into the Lake Tahoe Basin data base.

A data base, no matter how easily constructed and manipulated, is only as reliable as the elements which comprise it. Therefore, as new data are acquired, it is essential that these be tested and implemented into the data base to insure its viability. Although existing digital terrain imagery has proved difficult to adapt, Landsat data continues to work well within the data base concept. However, in terms of water quality, the subject lake and watershed area must be of such dimensions as to accommodate the resolution of the Landsat sensors.

Accurate correlation of changes in Lake Tahoe with various data elements contained

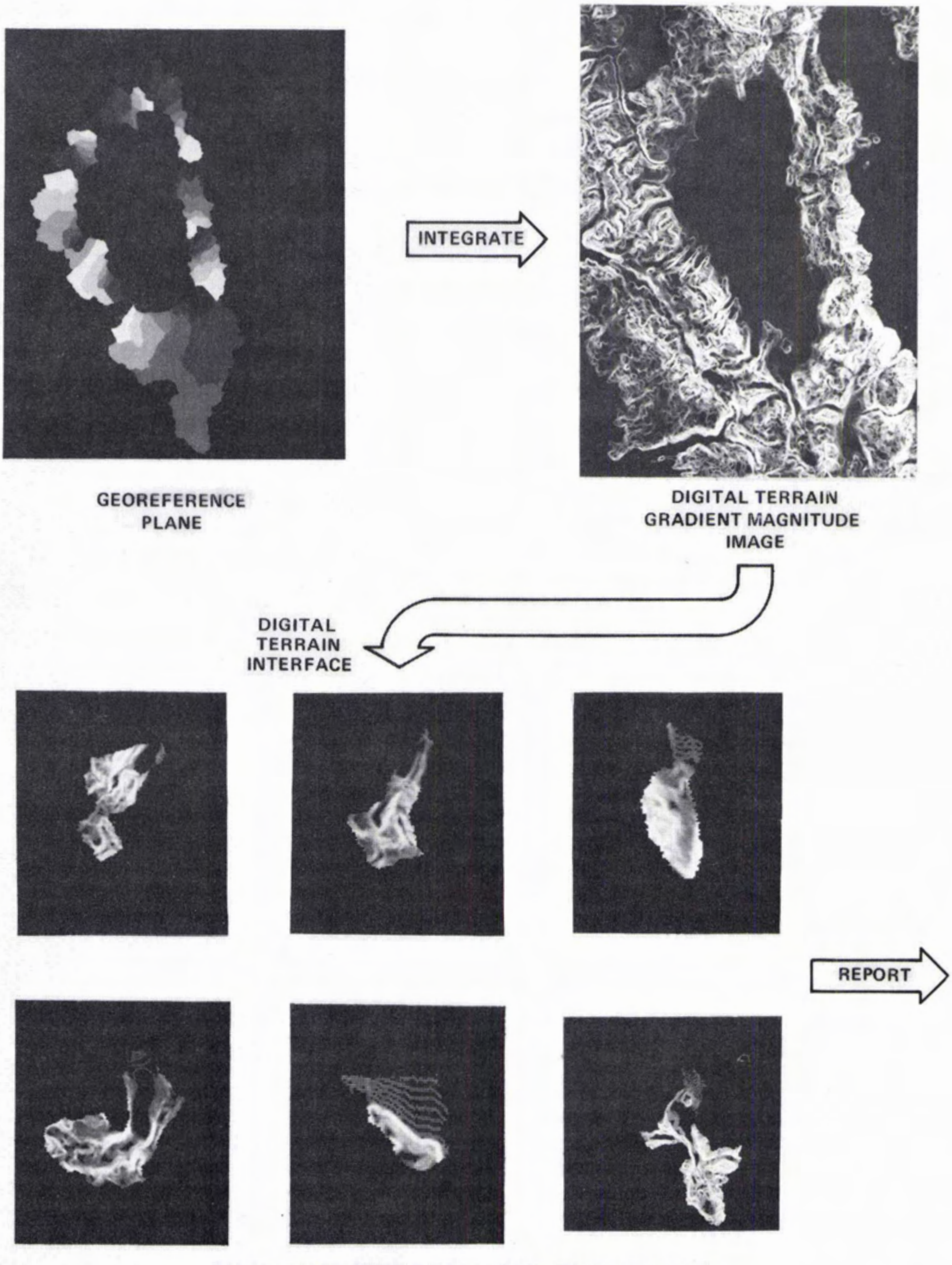


FIG. 6. The georeference plane has been interfaced with digital terrain data to extract individual basins and produce a statistical report (see Figure 7).

within the data base will require study over several years. It is hoped that the system over time can be used to monitor and evaluate causes for changes which effect the lacustrine environment. This will require the development of precipitation modelling, surface runoff models, and classification of drainage basin cover types. These elements must in turn be integrated and evaluated for accuracy before the system can be consid-

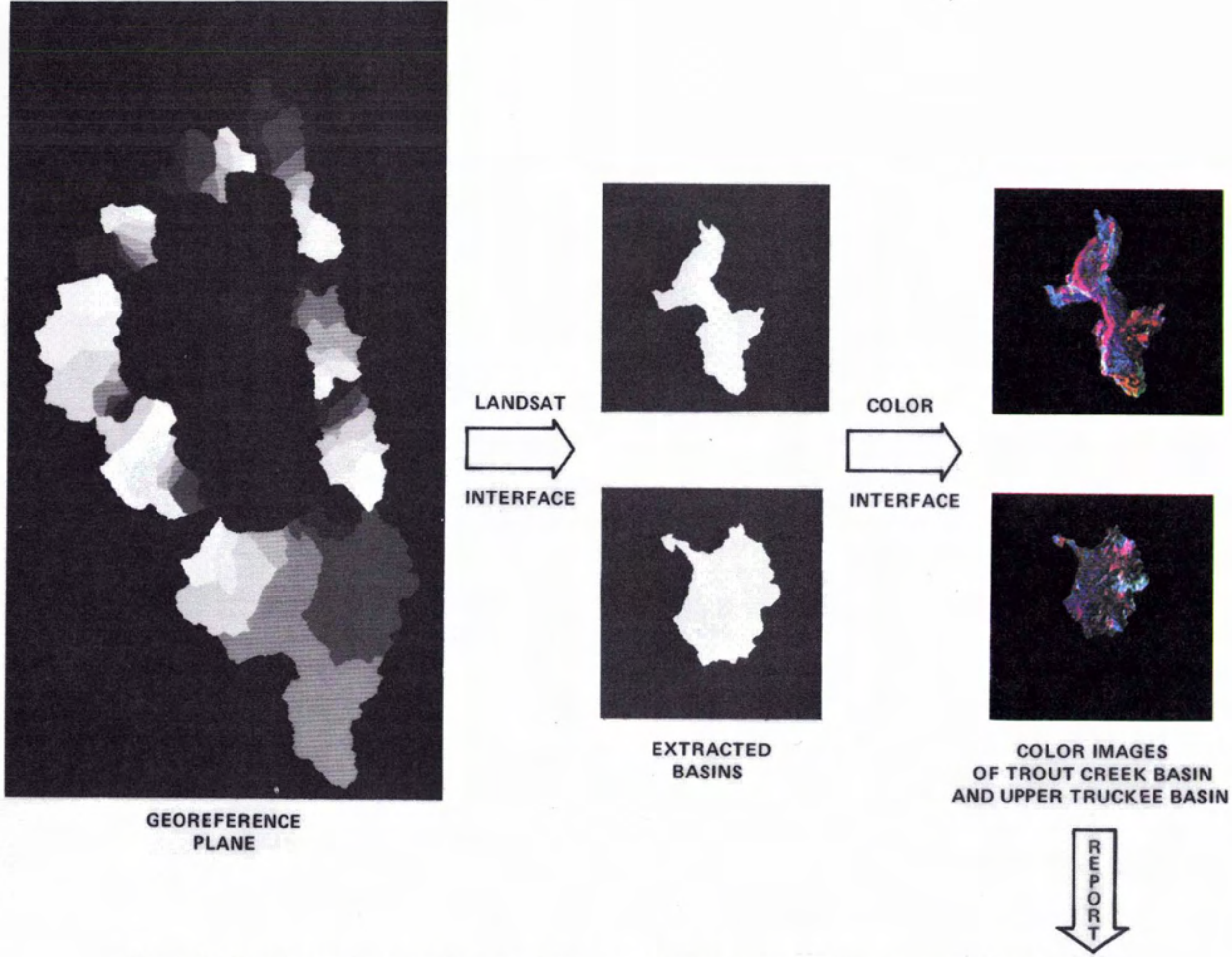
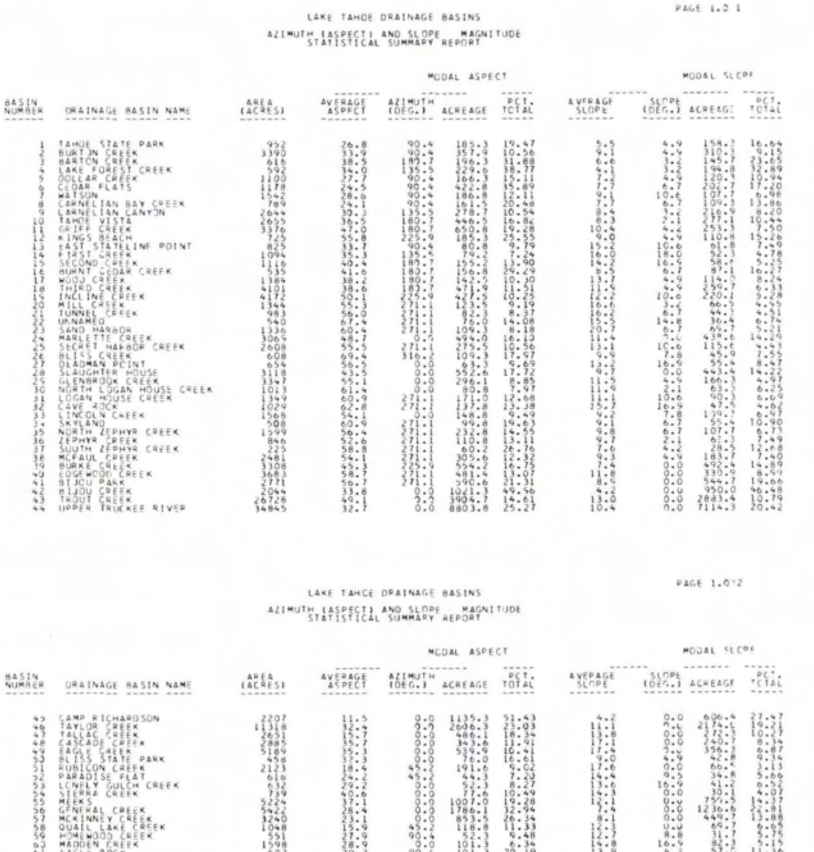


Plate 2. Interfacing the georeference plane with Landsat imagery allows access to each basin separately and generation of tabular reports.



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                                                                                        PAGE 1.0 1
                                         LAKE TAHOE DRAINAGE BASINS
                                  AZIMUTH (ASPECT) AND SLOPE   MAGNITUDE
                                         STATISTICAL SUMMARY REPORT

                                                        MODAL ASPECT                            MODAL SLOPE
                                               -------  -------  -----              ------  -------  -----
BASIN                                AREA    AVERAGE  AZIMUTH           PCT.  AVERAGE   SLOPE             PCT.
NUMBER   DRAINAGE BASIN NAME       (ACRES)    ASPECT   (DEG.)  ACREAGE  TOTAL   SLOPE   (DEG.)  ACREAGE   TOTAL
------   -------- ----- ----       -------   -------  ------- -------  -----  -------  ------ -------   -----

    1    TAHOE STATE PARK              952      26.8     90.4    185.3  19.47      5.5     4.9   158.3   16.64
    2    BURTON CREEK                 3390      33.9     90.4    357.9  10.56      9.1     4.9   310.3    9.15
    3    BARTON CREEK                  616      38.5    180.7    196.3  31.88      6.6     3.2   145.7   23.65
    4    LAKE FOREST CREEK             592      34.0    135.5    229.6  38.77      4.1     3.2   194.8   32.89
    5    DOLLAR CREEK                 1100      27.7     90.4    166.3  15.11      7.2     4.9   120.3   10.94
    6    CEDAR FLATS                  1178      24.5     90.4    422.8  35.89      7.7     6.7   202.7   17.20
    7    WATSON                       1542      28.6     90.4    186.8  12.11      9.1    10.6   107.7    6.98
    8    CARNELIAN BAY CREEK           789      24.1     90.4    161.5  20.48      7.7     6.7   109.3   13.86
    9    CARNELIAN CANYON             2644      30.3    135.5    278.7  10.54      8.4     3.2   216.9    8.20
   10    TAHOE VISTA                  2655      36.5    180.7    446.5  16.82      8.3     2.1   277.1   10.44
   11    GRIFF CREEK                  3376      47.0    180.7    650.8  19.28     10.4     4.2   253.3    7.50
   12    KINGS BEACH                   725      55.8    225.9    185.3  25.55      9.0     4.9   110.8   15.26
   13    EAST STATELINE POINT          825      33.7     90.4     80.8   9.79     15.2    10.6    61.8    7.49
   14    FIRST CREEK                  1094      35.3    135.5     79.2   7.24     16.0    18.0    52.3    4.78
   15    SECOND CREEK                 1116      40.4    180.7    155.2  13.90     14.2    16.5    58.6    5.25
   16    BURNT CEDAR CREEK             535      41.6    180.7    156.8  29.29      8.5     6.7    87.1   16.27
   17    WOOD CREEK                   1384      38.2    180.7    142.5  10.30     13.7     4.9   114.0    8.24
   18    THIRD CREEK                  4101      38.6    180.7    471.9  11.51     11.5     4.9   259.7    6.33
   19    INCLINE CREEK                4172      50.1    225.9    427.5  10.25     12.2    10.6   220.1    5.28
   20    MILL CREEK                   1344      55.3    271.1    123.5   9.19     16.6     3.2    66.5    4.55
   21    TUNNEL CREEK                  983      56.0    271.1     82.3   8.37     16.2     6.7    44.3    4.51
   22    UNNAMED                       540      67.4    271.1     76.0  14.08     15.5    14.8    36.4    6.74
   23    SAND HARBOR                  1336      60.4    271.1    109.3   8.18     20.7     6.7    69.7    5.21
   24    MARLETTE CREEK               3069      48.7      0.0    494.0  16.10     11.4     9.6   438.6   14.29
   25    SECRET HARBOR CREEK          2608      55.5    271.1    275.5  10.56     13.1    10.6   115.6    4.43
   26    BLISS CREEK                   608      69.4    316.2    109.3  17.97      9.9     7.8    45.9    7.55
   27    DEADMAN POINT                 654      56.5      0.0     63.3   9.69     13.2    16.9    55.4    8.47
   28    SLAUGHTER HOUSE              3118      43.5      0.0    552.6  17.72      9.7     0.0   443.4   14.22
   29    GLENBROOK CREEK              3347      55.1      0.0    296.1   8.85     11.5     4.9   166.3    4.97
   30    NORTH LOGAN HOUSE CREEK      1013      61.4      0.0     80.8   7.97     11.9     2.1    63.3    6.25
   31    LOGAN HOUSE CREEK            1349      60.9    271.1    171.0  12.68     11.1    10.6    90.3    6.69
   32    CAVE ROCK                    1029      62.8    271.1    137.8  13.38     15.7    16.9    47.5    4.62
   33    LINCOLN CREEK                1568      54.1      0.0    148.8   9.49      9.2     7.8   139.2    6.97
   34    SKYLAND                       508      60.9    271.1     99.8  19.63      9.1     6.7    55.4   10.90
   35    NORTH ZEPHYR CREEK           1599      56.4    271.1    232.8  14.55      9.8     6.7   107.7    6.73
   36    ZEPHYR CREEK                  846      52.6    271.1    110.8  13.11      9.7     2.1    62.3    7.49
   37    SOUTH ZEPHYR CREEK            225      58.8    271.1     60.2  26.76      7.6     4.2    28.5   12.68
   38    MCFAUL CREEK                 2481      54.1    271.1    305.6  12.32      9.3     4.9   183.7    7.40
   39    BURKE CREEK                  3308      45.3    225.9    554.2  16.75      7.4     0.0   492.4   14.89
   40    EDGEWOOD CREEK               3683      58.7    271.1    481.4  13.07     11.8     0.0   330.9    8.99
   41    BIJOU PARK                   2771      56.7    271.1    590.6  21.31      8.9     0.0   544.7   19.66
   42    BIJOU CREEK                  2044      33.8      0.0   1021.3  49.56      4.2     0.0   950.0   46.48
   43    TROUT CREEK                 26728      49.1      0.0   3904.7  14.61     13.0     0.0  2883.4   10.79
   44    UPPER TRUCKEE RIVER         34845      32.7      0.0   8803.8  25.27     10.4     0.0  7114.3   20.42


                                                                                        PAGE 1.012
                                         LAKE TAHOE DRAINAGE BASINS
                                  AZIMUTH (ASPECT) AND SLOPE   MAGNITUDE
                                         STATISTICAL SUMMARY REPORT

                                                        MODAL ASPECT                            MODAL SLOPE
                                               -------  -------  -----              ------  -------  -----
BASIN                                AREA    AVERAGE  AZIMUTH           PCT.  AVERAGE   SLOPE             PCT.
NUMBER   DRAINAGE BASIN NAME       (ACRES)    ASPECT   (DEG.)  ACREAGE  TOTAL   SLOPE   (DEG.)  ACREAGE   TOTAL
------   -------- ----- ----       -------   -------  ------- -------  -----  -------  ------ -------   -----

   45    CAMP RICHARDSON              2207      11.5      0.0   1135.3  51.43      4.2     0.0   606.4   27.47
   46    TAYLOR CREEK                11318      32.4      0.0   2606.3  23.03     11.1     0.0  2174.0   19.21
   47    TALLAC CREEK                 2651      15.7      0.0    486.1  18.34     13.8     0.0   272.3   10.27
   48    CASCADE CREEK                2885      35.7      0.0    343.6  11.91     17.1     0.0   240.7    8.34
   49    EAGLE CREEK                  5189      35.3      0.0    539.9  10.41     17.4     0.0   356.3    6.87
   50    BLISS STATE PARK              458      32.3      0.0     76.0  16.61      9.0     4.9    42.8    9.34
   51    RUBICON CREEK                2123      18.4     45.2    191.6   9.02     17.6     0.0    66.5    3.13
   52    PARADISE FLAT                 616      24.2     45.2     44.3   7.20     14.4     9.5    34.8    5.66
   53    LONELY GULCH CREEK            632      29.2      0.0     52.3   8.27     13.6    16.9    41.2    6.52
   54    SIERRA CREEK                  739      40.6      0.0     77.6  10.49     14.3     0.0    30.1    4.07
   55    MEEKS                        5224      37.1      0.0   1007.0  19.28     12.1     0.0   755.5   14.37
   56    GENERAL CREEK                5422      28.4      0.0   1786.1  32.94      7.4     0.0  1236.6   22.81
   57    MCKINNEY CREEK               3240      23.1      0.0    853.5  26.34      8.1     0.0   449.7   13.88
   58    QUAIL LAKE CREEK             1048      15.9     45.2    118.8  11.33     12.3     0.0    69.7    6.65
   59    HOMEWOOD CREEK                551      27.9     90.4     52.3   9.48     12.7     8.8    31.7    5.75
   60    MADDEN CREEK                 1598      28.9      0.0    101.3   6.34     14.8    16.9    82.3    5.15
   61    EAGLE ROCK                    502      29.3     90.4    101.3  20.19     13.9     4.2    57.0   11.36
   62    BLACKWOOD CREEK              7250      37.0      0.0    842.4  11.62     13.6     0.0   606.4    8.36
   63    WARD CREEK                   7958      30.1      0.0    858.2  10.78     11.2     2.1   574.8    7.22
   64                                 4093      30.0      0.0    440.2  10.75     11.9     0.0   316.7    7.74
                                   -------
                                    200095
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FIG. 7. The statistical report produced by interfacing the georeference plane with digital terrain data (see Figure 6).

ered usable. Such a system is feasible given the continued improvement of the remote sensing tools used to construct the data base and the data integrated into it. With the urban population continually encroaching upon delicate watershed systems such as Lake Tahoe, investigations into information systems for environmental monitoring will need to continue.

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