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Relevant and sufficient amounts of data are required to make correct and accurate decisions. Although some data are straightforward and easy to understand, other data—especially those with large quantity and sophisticated relationships to other data—could appear to be complicated, intimidating, and confusing. These data need to be processed and analyzed to reveal the patterns and relationships hidden in the large amounts of numbers. For example, while reviewing the historical records and reports of previous investigations at an environmentally impacted site, an environmental scientist gathers a large amount of datasets, such as historical drawings and aerial photos; chemical results of soil, surface water, sediment and groundwater samples; current and planned future land uses, hydrology, geology, soil, vegetation and elevation data; geophysical transects and anomalies and intrusive investigation results; water wells; wetlands; census data; cultural sites, habitats of protected species; affected properties; right of entry (ROE) information, and so on.

However, by looking at these datasets alone, it could be hard to locate the environmentally impacted areas, delineate their extents on the surface and underground, visualize their patterns and relationships, and understand their changes over time. It could also be difficult to evaluate their current and possible future risks to human health, the environment and the ecosystem and to design remedial investigation strategies and detailed technical approaches. Scientists and decision-makers could be confused by these large quantities of datasets piled up on their desks. No matter how valuable these datasets are and how much money and time are spent collecting them, if data users are not able to fully understand them and visualize their relationships, patterns, and trends, the values of the data are not fully utilized. They will not help much in precisely understanding problems and finding solutions. In extreme cases, if data users are confused or misled by the large and complex datasets, they might make inaccurate or even wrong decisions. Therefore, more data do not always result in better decision-making.

A Geographic Information System (GIS) offers powerful data processing, analyzing, and modeling tools to help scientists and decision-makers to visualize and understand data better, to get useful and more meaningful information from them, and to make sound decisions when solving problems. For example, with GIS, a historical aerial photo showing features of
form former air-to-ground practice bombing ranges, targets, and bombing craters can be georeferenced and overlain onto a current map. This enables locating the areas impacted by the bombing-related military munitions, including unexploded ordnance (UXO), munitions debris (MD), and munitions and explosives of concern (MEC). It also helps in delineating their boundaries and designing investigative and/or remedial approaches, such as obtaining ROE to the affected properties; planning brush clearance; deciding sampling types and locations; proposing geophysical survey methods, areas, and transects; designing intrusive investigation grids and/or trenches; and installing monitoring wells.

Similarly, a historical drawing showing the detailed layout of an installation can be scanned and georeferenced to identify potential polluted areas and their possible sources, such as ground and underground fuel or munitions storage facilities; fueling stations; hazardous materials loading, unloading and processing areas; maintenance shops; landfills/dump areas; and burial pits. Analytical results of samples can be statistically analyzed and displayed as color-shaded contour maps showing concentration patterns throughout the whole project site and changing trends over time. Underground soil and water contaminations can be delineated and illustrated using three-dimensional (3D) modeling and visualization techniques. Risks to human health, the environment, and the ecosystem can be evaluated by analyzing the relationships between the related data layers, such as samples, census data, water wells, groundwater aquifers, wetlands, rivers, streams, lakes, oceans, parcels, habitats, geology, soil, land covers and uses, and topography. By statistically analyzing existing data coverage of a project site, data clusters (i.e., too much and overlapping data areas) and data gaps (i.e., insufficient data coverage areas) can be identified and situations in adjacent areas can be predicted. For data gaps, additional data collection efforts are required to achieve sufficient data coverage of the whole project site to make accurate decisions. In areas with data clusters, monetary savings can be achieved by avoiding new data collecting efforts there and by reducing some existing data collection activities, for example, decommission unnecessary monitoring wells and remove unwanted sampling locations.

Case Study 3.1: Statistically Analyzing Existing Geophysical Survey Data to Predict Possible Anomalies in Adjacent Unknown Areas

Site 8, located in the south central portion of the former Camp Sibert, was a 375 acre area within the former Range R30 that had been impacted by toxic chemical munitions. Topographically, Site 8 is characterized by relatively flat lowlands and floodplains. The general vegetation of Site 8 consists of mixed
pine and hardwood forest. The northern section of Site 8 is covered by a thick
intermediate pine forest; its central section was cleared for grazing land, and
its southern section is undeveloped and covered by thick pine and hard-
wood forest.

From early 1942 to late 1945, during the Second World War, Range R30 was
constructed and used as a toxic gas 4.2 in. chemical mortar training range.
Site 8 was the impact area within Range R30. Inside the 4.2 in. mortar range,
a Japanese-style pillbox was constructed for jungle warfare and pillbox-
attack training purposes. The 4.2 in. mortar was historically used in training
to fire chemical or smoke rounds filled with mustard, phosgene, lewisite,
tearing agents, white phosphorus, sulfur trioxide, chlorosulfonic acid solu-
tions, etc. Training in Range R30 and Site 8 ended after the war in late 1945
and the site was closed. In June 1948, a chemical mortar round in the back of
a pickup truck was accidentally detonated near Site 8 and the people inside
the vehicle were injured with mustard-agent-type burns.

A chemical warfare materiel (CWM) removal action (RA) at Site 8 was ini-
tiated in June 2004 to remove and dispose of all recovered CWM, ordnance-
related scraps, and explosives hazards from selected areas—totaling around
247.73 acres—of Site 8. The southern, heavily forested section of Site 8 was
not included in that RA project.

Before this RA project was carried out, all the geophysical survey and
intrusive investigations datasets from previous investigations were retrieved
and reviewed. Project records show that during an engineering evaluation/
cost analysis (EE/CA) investigation in 2000 the central portion of Site 8 was
gophysically surveyed using meandering paths and 532 anomalies were
identified. Another phased EE/CA investigation was conducted at Site 8 in
2002. The site was geophysically mapped using towed arrays, with 8673
more anomalies identified. The surveyed (mapped) geophysical anomalies
of these two previous EE/CA investigations were combined (totaling 9205)
and are shown as red dots in Figure 3.1.

GIS statistical tools and functionalities were used to analyze these sur-
veyed geophysical anomalies to predict possible anomaly distribution pat-
terns in the adjacent unknown and un-surveyed areas based on the Kriging
geostatistical method.

The basic Kriging method was developed by the French mathematician
Georges Matheron, based on the studies and experiments of Danie G. Krige,
a South African mining engineer who tried to predict the most likely dis-
tribution of gold based on the samples from a few boreholes using some
statistical calculation methods. Acknowledging Krige’s pioneering work,
this unique statistical analysis method was named after him. The Kriging
method, also known as Gaussian process regression, is a widely used statis-
tical data point interpolation technique that uses existing measured/known
data values to calculate a predicted value in an unmeasured/unknown adja-
cent location based on the assumption that the spatial variation in the data
being modeled is homogeneous across the entire study area.
There are other, similar regression-based statistical interpolation algorithms and methods, such as inverse distance squared, splines, radial basis functions, triangulation, and so on. They all predict the value at an unknown location as a weighted sum of data points at its surrounding locations. Weights are calculated and assigned based on the distance of the prediction locations from the measured points, directions, and the overall distribution patterns of the measured points of the area of interest. Distance is the most important factor. Weights decrease with increasing separation distance of the predicted point and its surrounding measured data points.

What makes Kriging unique among interpolation methods is that it calculates and assigns weights based more on a data-driven weighting function, rather than an arbitrary function, and it also offers a way to estimate the variance of predictions, that is, estimation errors.

Regardless of the interpolation algorithm chosen, high-quality datasets usually yield more accurate prediction results, and vice versa. In general, if known data points are accurate, relatively dense, and uniformly distributed throughout the study area, the calculated predictions are more reliable. However, if the data points are scarce or in clusters with large data gaps in between, it will be hard to achieve an accurate prediction no matter which interpolation algorithm or method is used.

In Kriging, there are different methods for calculating the weights (i.e., Kriging variants), such as simple Kriging, ordinary Kriging, universal
Kriging, IRFk-Kriging, indicator Kriging, multiple-indicator Kriging, disjunctive Kriging, and lognormal Kriging.

Following are three main Kriging variants discussed in more detail.

- **Simple Kriging**: With a simple Kriging method, it is assumed that the mean is constant over the entire domain of interest. It is an unbiased weight estimating approach. It calculates the value of the prediction location based on a set of weights estimated from a set of neighboring data points. The weight on each data point decreases with increasing distance to the prediction point; that is, closer data points have more influence on the prediction point than the more distant ones. It also decreases the weights of data points in clusters, instead of treating them the same way as normally distributed data points. This is one of the advantages of Kriging when compared with other data point interpolation algorithms.

- **Ordinary Kriging**: Slightly different from simple Kriging, ordinary Kriging assumes that the mean is constant in the local neighborhood of a prediction point, instead of the entire study area.

- **Universal Kriging**: Quite different from simple Kriging and ordinary Kriging variants, in universal Kriging the mean can be non-constant, allowing for local variations.

As Figure 3.1 demonstrates, the mapped geophysical anomalies, that is, the red data points, are fairly dense and uniformly distributed throughout the study area except for in the suspect impact area. This is the section inside the dashed cyan circle, where more anomalies were recorded. Even in this area, data points are relatively evenly distributed without any clusters or data gaps. Therefore, the simple Kriging method was selected to predict possible anomalies in the adjacent un-surveyed areas from the mapped geophysical anomalies. The results are shown as yellow points in Figure 3.1.

The distribution pattern/trend of the predicted anomalies corresponds very well with the pattern of the mapped anomalies, that is, there are more anomalies inside and near the suspect impact area and gradually fewer and fewer anomalies moving farther away from it.

Since the southern portion of Site 8 was not included in the scope of the RA project, the predicted anomaly points in that area were manually cleared from the map. This geophysical anomaly distribution map, showing both the mapped and predicted anomalies, was used by both the RA project team and the field crews to acquire right of entry (ROE), plan brush clearing areas, design additional geophysical survey areas, design intrusive investigation grids system, position vapor containment structures (VCS), and calculate safety exclusion zones. Using this GIS data analysis technique saved the project time and money.
Case Studies 3.2, 3.3, 3.4, 3.5: Analyzing Recent, Historical Aerial Photos/Drawings and LiDAR to Identify and Delineate Environmentally Impacted Areas

Case Study 3.2: Recent Aerial Photo Analysis

Encompassing approximately 4900 acres of land, Site 19 is the largest site inside the former Camp Sibert. It was impacted by the conventional mortar training conducted from 1942 through 1945. In 1995, during Phase II of the Site Characterization project, a limited geophysical survey was conducted and around 341 subsurface anomalies were identified. The Phase II Site Characterization Report recommended additional geophysical mapping along with intrusive investigations that would include excavating a a certain number of the identified subsurface anomalies.

During a remedial investigation/feasibility study (RI/FS) project of Site 19 in 2002, the project team reviewed all previous investigations of Site 19, including the Site Characterization Report and the anomalies data. Constrained by the tight project budget and schedule for this large site, innovative approaches had to be utilized to save the costs of the recommended geophysical mapping and intrusive investigations. The most important approach was to identify and delineate the areas of the greatest concerns using GIS technology. The theory is that most ordnance and explosive (OE) wastes, such as unexploded ordnance (UXO) and munitions debris (MD) from conventional weapons, are usually on the surface or buried relatively shallowly in the ground. Therefore, the areas disturbed by construction, farming, or other activities are unlikely to still have OE wastes. So, investigations should be focused on the areas undisturbed since 1945, instead of conducting geophysical mapping and intrusive investigations on the whole large site. This was nearly impossible in any case with the limited project budget and schedule.

To achieve the cost-saving goals and ensure the project ran on schedule, GIS raster image analysis techniques were used to analyze the high resolution and relatively recent 1997 aerial photos to identify the undisturbed areas inside Site 19. The 1997 aerial photos were selected for analysis because of their high resolution and also because not much ground disturbance had occurred in Site 19 since they were taken. Some 1950 aerial photos were also analyzed to further enhance and confirm the 1997 aerial analysis results, as shown in Figure 3.2.

As discussed in Chapter 2, there are numerous methods to identify and extract features from satellite images, aerial photos, LiDAR data, scanned images, and so on. One of the most commonly used methods is to classify pixels based on their physical properties, that is, the values of the pixels. Adjacent pixels with similar values are grouped or classified together by a range of values and separated from their neighboring pixels with significantly
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FIGURE 3.2
1997 aerial photo analysis results of Site 19, former Camp Sibert. The green areas (around 3200 acres) are the calculated undisturbed areas, where geophysical survey mapping and intrusive investigations were mainly focused. The blue line represents the boundary of Site 19, with around 4900 acres. The brown lines represent the firing fans.

different values, to form patterns. Through analyzing similar and different patterns, features in an image can be identified and recognized. In Site 19, undisturbed areas are mainly covered with thick vegetation, while disturbed areas are usually bare surfaces, such as roads, farms, and developed properties. Their contrasting differences form the boundaries of the features.

During the image processing and analysis process, some errors were unavoidably introduced. Therefore, the extracted features from the aerial photos were then converted into vector data format using a GIS raster-to-vector conversion tool. They then could be further cleaned up and edited to better represent the true conditions of the project site.

The calculated total acreage of the undisturbed areas derived from the image analysis was around 3200 acres, around 65% of the whole 4900 acre site.
By focusing a geophysical survey and an intrusive investigation on these identified undisturbed areas instead of the whole site, savings of about one-third of the cost were achieved. The focused investigating areas were further reduced by overlaying them with firing fans, also shown in Figure 3.2. Since the areas within the firing fans were more likely to be impacted than the areas outside the firing fans, investigations were more focused on them. Other areas, less likely to be impacted, were also sampled, selectively surveyed, and intrusively investigated to ensure a sufficient amount of data was collected throughout the whole project site.

Case Study 3.3 (Site 2A of Former Camp Sibert) and 3.4 (Tanapag Fuel Farm): Analyzing Historical Aerial Photos and Drawings

In 2009, the Chemical Agent Contaminated Media Removal Action (RA) and the Remedial Investigation/Feasibility Study (RI/FS) projects were conducted at Site 2A, which is situated in the central portion of the former Camp Sibert. Site 2A was formerly used for chemical agent decontamination training and also as a burial site for training materials. Training at Site 2A was mainly decontamination training on an airplane fuselage as well as on walls, floors, different road types (gravel, concrete, sand and macadam), shell holes, and trucks. In addition to the burial pits, the site also contained a mustard soakage pit, a chemical agent storage area, a supply building and a shower/dressing facility. Historical records and previous investigation reports indicate that the chemical agents used for training or buried at Site 2A include mustard, nitrogen-mustards, and lewisite. Industrial chemicals such as phosgene, fuming sulfuric acid, tearing agent and adamsite might also have been used. At the end of World War II in late 1945, training activities at former Camp Sibert ended and the whole site was closed. CWM-related materials and equipment left over from the training were buried at Site 2A in three burial pits and excess chemical agents were poured into a soakage pit.

GIS image analysis techniques were used to locate and delineate the decontamination training areas, burial pits, mustard soakage pit, chemical agent storage area, supply building and shower/dressing facility. Historical drawings, showing the training and burial layout of Site 2A, were scanned, georeferenced, and overlaid on a recent aerial photo to identify these impacted areas, as shown in Figure 3.3. Historical aerial photos were also processed and analyzed to confirm the impacted areas identified from the drawing and to further refine their locations and boundaries.

These kinds of information were very useful for the project team and their field crews in selecting affected properties and obtaining ROE; planning brush clearing; constructing site access roads; designing geophysical survey areas; and identifying soil, surface water, sediment and groundwater sampling locations. This information also fed into the work to identify intrusive investigation approaches and to calculate safety zones, as shown in Figure 3.4.
FIGURE 3.3
A 1944 historical drawing showing the layout of Site 2A. It was scanned, georeferenced, and overlaid on a recent aerial photo to locate and delineate the burial pits, mustard soakage pit, chemical agent storage area, supply building, shower/dressing facility and the decontamination training areas for the airplane fuselage, walls, floors, roads, shell holes, and trucks. The red lines represent project sites. The middle one is Site 2A. The blue line polygons are the identified impact areas, including three CWM burial pits in the north of Site 2A and a mustard soakage pit, a chemical agent storage area, a supply building and a shower/dressing facility, truck decontamination area and shell holes decontamination area in the south of Site 2A.
The next case study (i.e., case study 3.4) discusses how historical aerial photos were processed and analyzed to locate fuel storage tanks in the Tanapag Fuel Farm (TFF), a formerly used fuel storage facility (also known as a fuel farm) in Tanapag village in the northwestern section of Saipan Island. Saipan is the largest island of the Commonwealth of the Northern Mariana Islands (CNMI), a north–south trending chain containing 16 small islands in the tropical Western Pacific. Saipan, with an area of about 48 square miles and a population of approximately 65,000, is the center of government, transportation, commerce, and education for the CNMI.
The former TFF actually contains two separate sites, the northeast site and the southwest site, which lie approximately 0.6 mile apart at their closest points. The smaller, 4.8 acre southwest site is located in the region known as Puerto Rico, while the larger, 96 acre northeast site is located in the village of Tanapag. Classified as a tropical marine climate zone, Saipan is warm and humid throughout the year, with an average temperature of around 75°–80°F and a mean annual rainfall of 80 in.

Historically, Saipan was under the control of Japan for some time, until U.S. forces invaded it in June 1944, during World War II. The fuel farm was built by U.S. forces to supply fuel oil, diesel fuel and aviation gasoline for U.S. Navy ships and aircraft during World War II and through the 1950s, after which the fuel storage tanks were abandoned. Declassified records and previous reports indicated that between 40 and 47 above-ground tanks were constructed at the two TFF sites, with the majority of the tanks located at the northeast site and only a few at the southwest site. The tanks fall into three broad categories: the 10,000 barrel (bbl) tanks for special Navy fuel oil; 10,000 bbl tanks for diesel fuel; and 1,000 bbl tanks for aviation gas. In addition to the fuel storage tanks, there were numerous connecting pipelines, pump houses and 1.2 miles of submarine lines for each type of fuel.

Due to both human activity and the elements, these abandoned fuel storage tanks were partially or completely collapsed, rusted, corroded, crushed, or simply left as piles of metal debris. They became physical and chemical hazards to human health and the environment. Chemical hazards include total petroleum hydrocarbons (oil) as the primary contaminant of concern and also some metals such as arsenic, cadmium, chromium and iron.

The primary objectives of the proposed RA project included a biological survey for endangered species; brush clearance and access road improvements; demolition and recycling of around 17 tanks (including disposal of sludge and residual fuel); sampling and characterization of wastes for disposal; and an environmental investigation of impacts on soil, surface water, and groundwater related to the tanks.

During review of historical records and previous investigation reports, discrepancies were found regarding the total number of the above-ground fuel storage tanks and their locations. It was suspected that the locations of some of the tanks were significantly inaccurate. Therefore, GIS image analysis tools were used to process and analyze historical aerial photos of the mid- to late 1940s and 1950s to accurately locate the tanks. Figure 3.5 is an analyzed 1946 high-resolution aerial photo map (top) showing the tank locations at the northeast site of the TFF, while the bottom is a picture of a collapsed tank. Other historical aerial photos were also processed and analyzed to confirm the tank locations in both the northeast and southwest sites.
Case Study 3.5: Analyzing High-Resolution LiDAR Data

A large (approximately 12,831 acres) formerly used defense site (FUDS) in central Louisiana state was used for air-to-ground bombing and small arms training in the 1940s. After the training ended and the FUDS closed in the early 1950s, the property was transferred to the U.S. National Forest Service (NFS). There were several reports about OE items encountered by NFS employees in the FUDS. In 2005, a site inspections project was conducted at this munitions and explosives of concern (MEC) impacted site. Since the entire large site was covered with heavy vegetation, it was difficult to locate the MEC-impacted areas because the features brought about by the historical bombing and firing related activities were not visible on the ground. Not enough historical drawings or aerial photos could be found to identify the impacted areas either. Also, since the site is so large and located in a national forest, it was virtually impossible to clear the vegetation from the whole site. Therefore, light detection and ranging (LiDAR) technology, which can penetrate thick vegetation, was used to survey the site to locate the features and delineate the impacted areas.
LiDAR is a remote sensing technology that uses light in the form of a pulsed laser to measure distances to the Earth. The light pulses, which can penetrate vegetation, combined with other data recorded by the airborne system, can generate high-resolution 3D information about the shape of the Earth’s surface. The LiDAR survey data were processed with GIS image analysis techniques to produce high-resolution 3D images of the MEC-impacted site, as shown in Figure 3.6. The processed LiDAR images clearly show the features from the historical training activities, such as bombing craters, firing lines, berms, site access roads and so on. With these features identified, the MEC-impacted areas were located and their boundaries were accurately delineated. Site investigation approaches were designed to focus on the MEC-related areas to minimize impacts to the habitats of the protected species, wetlands, soil, and plants in the national forest.

**Case Study 3.6: Topographic Slope Analysis**

Slope (also known as grade, gradient, incline, pitch or rise) information is very important in civil engineering, environmental investigations, geology, hydrology, transportation, agriculture, mining, conservation, infrastructure...
and many other applications. In mathematics, a slope is defined as the ratio of the vertical change to the horizontal change of a surface. The vertical change is called the rise, while the horizontal change is called the run.

There are two different ways to express a slope. One is the angle of a slope in the range of 0°–90°, and the second is to assign it a percentage gradient, also known as a percent rise. The degree of a slope is calculated as the arc-tangent (also commonly known as arctan, atan, or tan^−1) of the angle of the inclined surface to the horizontal surface (i.e., \(\text{degree of the slope} = \text{arctan} \left(\frac{\text{rise}}{\text{run}}\right)\)). The percent of a slope is calculated as the rise divided by the run and multiplied by 100 (i.e., \(\text{percent of the slope} = \left(\frac{\text{rise}}{\text{run}}\right) \times 100\)).

For example, when a slope's angle is at 45°, the rise is equal to the run. Therefore, the percent of the slope is 100%. When the slope angle decreases to 0°, the percent of the slope also becomes 0%, because the rise is 0. When the slope angle approaches 90°, that is, near vertical, the run approaches 0 and therefore the percent of the slope begins to approach infinity. Therefore, the percentage range of the slope is from 0 to near infinity. In other words, a flat surface is 0%, a 45° slope is 100%, and as the slope becomes steeper toward vertical, the percent gradient increases toward infinity. Regardless of the slope unit (angle or percent gradient), the lower the slope value, the flatter the terrain surface is. The higher the slope value, the steeper the terrain is. The conversion between these two slope types is \(\text{degree of the slope} = \text{arctan} \left(\frac{\text{percent of the slope}}{100}\right)\).

An inclined surface has two properties: its slope (the maximum rate of change of the elevation of the surface) and its aspect (the facing direction of the surface with respect to the north). Aspect is measured clockwise in degrees from 0 (due north) to 360 (again due north) forming a full circle. With respect to its facing direction or aspect, the slope value of a surface can be either positive or negative. An upward surface has a positive slope value, while a downward surface has a negative slope value. A flat surface has a zero slope.

For environmental investigations, especially ones requiring walking or driving around the site for visual reconnaissance and geophysical survey mapping, topographic slope information is needed to design visual reconnaissance paths (also known as qualitative reconnaissance tracks) and geophysical survey paths (also known as transects). Some geophysical survey equipment, such as carried, cart-mounted, or towed-array geophysical systems, cannot be used in areas with steep slopes, for example, those near or above 30°. Also, for a site contaminated by ordnance and explosive waste, investigations should be focused more on downslope areas and less on upslope areas, because MECs, MDs, and MCs are usually found on the surface or relatively shallow in the ground and therefore move down on slopes.

This case study is the FUDS Military Munitions Response Program (MMRP) Remedial Investigation/Feasibility Study (RI/FS) of the former Waikoloa Maneuver Area on the Island of Hawaii. In December 1943, the U.S. Navy acquired approximately 91,000 acres of land from a private ranch. Portions of the land were used as an artillery firing range, while other
portions were used for troop maneuvers. Intensive live-fire training was conducted in forested areas, cane fields, and around the hills. Weapons used in the training exercises include carbines, rifles, bazookas, flame-throwers, hand grenades, mortars and machine guns, and so on. They also test-fired packages of Japanese language surrender leaflets. Infantry regiments conducted maneuvers with fighter and dive-bomber support. There was also other training with demolitions, mines, and other special equipment, such as construction equipment (e.g., cranes, bulldozers, and tractors), tanks, weapon carriers, trucks and jeeps. After World War II, the training site was closed.

The current and future land uses are mainly residential, agricultural, pastoral, conservational, industrial, and resort/recreational uses. Topographically, it is divided into two landforms, the steep sloped upland areas and the gentle sloped lava plains. The upland is cut by widely spaced gullies formed by erosion.

For this large project site, many 7.5-minute quadrangles of the U.S. Geological Survey (USGS) Digital Elevation Model (DEM) data and some higher-resolution (1 meter) National Elevation Dataset (NED) data were obtained and used for slope analysis, depending on data availability of the areas.

The DEM is a more commonly used generic term for digital elevation data. There are other terms and formats of this kind of elevation data, such as digital terrain model (DTM) and digital surface model (DSM). In the 1970s, the USGS started producing DEMs from aerial imagery using manual stereoplotters. Since then, numerous methods have been developed to produce DEM data more efficiently and accurately, especially by remote sensing technologies, such as the SPOT 1 satellite, the European Remote Sensing Satellite (ERS), the Shuttle Radar Topography Mission (SRTM), and others. The major DEM data providers include USGS, CGIAR, Spot Image, and the Earth Remote Sensing Data Analysis Center (ERSDAC, now ‘Japan Space Systems’). Starting in early 1990s, the USGS has been producing seamless elevation data, named National Elevation Datasets (NED), covering the United States, Hawaii, and Puerto Rico from its older DEMs and other sources.

GIS spatial analysis tools were utilized to process and analyze USGS DEM and NED datasets to calculate slopes at this large MMRP site. In GIS, for each raster cell, its slope is derived by calculating the maximum rate of change in elevation value from the subject cell to its eight neighboring cells in a 3×3 cells window. The subject cell is at the center of the 3×3 cells window. By moving this window, the slope of every cell in the elevation raster dataset is calculated.

Figure 3.7 is an example slope analysis results map of Project 20 (also named as Sector 16) located in the northern portion of the former Waikoloa Maneuver Area (see the Index Map of Figure 3.8). The northern part of Project 20 is the steep sloped upland in the foothills of the Kohala Mountains with some four-wheel drive (4WD) trails (dashed lines
FIGURE 3.7
Slope analysis map of Project 20 located in the northern portion of the former Waikoloa Maneuver Area. The red areas represent steep slopes (>30°), the yellow areas representing moderately steep slopes (20°–29°) and the green areas representing a gentle slope (<19°). This slope analysis map is useful in designing field work activities, such as qualitative reconnaissance tracks, geophysical transects and intrusive investigations, as shown on Figure 3.8.

FIGURE 3.8
Proposed field work map of Project 20 of the former Waikoloa Maneuver Area based on the slope analysis results. The spacing and orientation of the qualitative reconnaissance tracks (purple lines) and geophysical transects (black lines) were designed based on the slope analysis of the project site. The red areas represent steep slopes (>30°), the yellow areas represent moderately steep slopes (20°–29°), and the green areas representing gentle slopes (<19°). Qualitative reconnaissance, geophysical survey and intrusive investigations are more focused in the downslope areas as compared with the steep upslope areas. Also, proposed qualitative reconnaissance tracks and geophysical survey transects follow the general topographic elevation contour lines to minimize climbing the steep slopes.
in Figure 3.8). The southern part of Project 20 is a strip of gently sloped lava plain.

Due to these contrasting topographic characteristics, Project 20 is divided into two investigation sections with different approaches. As displayed in Figure 3.8, investigation will be more focused on the relatively flat area in the south, with dense planned qualitative reconnaissance tracks, geophysical transects, and intrusive investigation grids. In the northern part, with challenging steep sloped terrains, relatively less transects are planned. Also, planned transect lines are oriented following the general slope patterns of the terrains (i.e., along elevation contours) to avoid steep climbing against the slopes.

**Case Study 3.7: Geophysical Anomaly Density Analysis**

A remedial investigation and feasibility study (RI/FS) project and RA project were conducted at seven conventional MEC-impacted sites and four suspected CWM-impacted sites inside former Camp Sibert in 2010 and 2011 (as shown in Figure 3.9). The primary goal of the remedial investigation (RI) was to collect a sufficient amount of data to determine the nature and extent of MEC, CWM and MC pollution. The data and results from the RI were then used by the Feasibility Study phase of the project to develop and evaluate effective remedial alternatives. During the RI, datasets collected from the digital geophysical mapping (DGM), the intrusive investigation of geophysical anomalies, and the mag-and-dig investigation were used to assess the nature and extent of MEC and MC. The term “mag-and-dig” refers to an investigation method of using an analog geophysical instrument to locate an anomaly, marking the detected anomaly with a flag and excavating the flagged location to determine the item(s) buried there.

During the project’s FS phase, different remedial alternatives were developed and assessed for managing risks associated with potential MEC and MC contamination. Its main purpose was to provide decision-makers with the necessary data to further evaluate and select the final remedies for the sites. The analysis of the density of MEC and MD is one of the most important factors in developing and evaluating the remedial alternatives for a site.

A large volume of the datasets from a variety of previous investigations and the current RI project were compiled, processed, and statistically analyzed to generate the MEC/MD density maps for the whole former Camp Sibert, as well as the individual sites selected for these RI/FS and RA projects.

Basically, density is the result of quantity divided by area, that is, the magnitude of something per square unit. In statistics, density analysis is a type
FIGURE 3.9
A GIS map showing RA and RI/FS project sites inside the former Camp Sibert. Some of the sites are conventional Munitions and Explosives of Concern (MEC) impacted sites, while others are suspected chemical warfare materiel (CWM) impacted sites, or both MEC and CWM.
of spatial interpolation, which analyzes the spatial relationships, patterns, and trends of the measured/known quantities of samples and spreads them across the whole study area based on a data interpolation method. Densities of both point and line features can be calculated. Line density calculates the density of linear features in the neighborhood of each output raster cell, in the unit of length per square unit of the area of interest, for example, the density of streams in a watershed study area, the density of roads in a proposed distribution warehouse area and the density of fractures and/or faults in an engineering project area.

However, point density information is more commonly used in research, studies, planning, and others, such as population density of a region, crime density of a neighborhood or city, accident density of a traffic study area, geophysical anomaly density of an environmental project area, and many more.

There are two density analysis methods in GIS: point density and line density, with simple and kernel options. For a point density analysis with the simple option, the study area is divided into a raster grid, using the cell size input value. Then, a search circle is drawn around each raster cell center using the search radius input value. All the points within the search circle are multiplied by its population (also known as weight) field value in the point feature’s attribute table, summed, and divided by the circle’s area to get the density of the raster cell. The population field value assigns weight to the data point location. It is basically the quantity at that spatial location, for example, the number of people at an address, the number of crimes recorded at a location over a certain period of time, or the number of geophysical anomalies discovered in a survey location. The smaller the cell size, the higher the output data resolution is. The larger the search radius, the larger the search circle is. Therefore, more data points are included in each cell calculation. It is important to understand the characteristics of the data points and the study area to set the appropriate cell size and search radius to achieve more accurate and meaningful density calculation results.

Similar to the point density method, line density analysis measures the length of the portion of each line that falls within the search circle, multiplies the length by its population field value in the line feature’s attribute table, adds them together, and divides the total by the circle’s area to get the line density of the raster cell.

What the kernel option does in a point density analysis process is fit a smoothly curved surface over each data point location where the surface value is the highest and then decreases gradually with increasing distance away from the data point until reaching zero at end of the data point’s search radius. The density of each grid cell is calculated by adding the values of all the kernel surfaces where they overlay the grid cell center. The kernel option usually produces a smoother density surface over a large area than the simple option. However, in a large area with data clusters and big data
gaps between them, such as the MEC/MD data points shown in Figure 3.10, the kernel option could produce an inaccurately smooth density surface over the study area by overstretching/smoothing the data points to fill the data gaps.

If not specified, density analysis in GIS will use the extent of the input data layer as the boundary of the calculation. Therefore, points on the edges of the data layer will have truncated densities. However, in most cases, it is usually desirable to have density calculated slightly beyond the data points. This can be achieved by selecting a slightly larger polygon layer as the extent of the density calculation, in the “environments” setting of the density analysis process.

Figure 3.10 shows the MEC/MD density patterns of multiple sites inside the former Camp Sibert. It was calculated using the point density method with the simple option, using the project site boundaries as the extents. A variety of cell sizes and search radius values were experimented with to achieve the most accurate, reasonable, and meaningful density results, which were evaluated based on the datasets and knowledge of the conditions of the project sites. Figure 3.11 is a MEC/MD density map of Site 18, which is located in the southeastern section of the former Camp Sibert.

The MEC/MD density analysis results and other relevant data were used in the FS to develop and screen the seven remedial alternatives, which are briefly explained as follows:

1. No Further Action (NFA): No action is needed for the site.
2. Educational Awareness: A site-specific educational awareness program is needed, such as fact sheets, public involvement, and so on.
3. Surface MEC Removal with MC Contaminated Soil Removal at UXO Detonation Locations: Only MEC items on surface and surface soil contaminated by munitions constituents at UXO detonation locations are required to be removed.
4. MEC Removal to 1 Foot Depth with MC Contaminated Soil Removal at UXO Detonation Locations: MEC items and soil up to a depth of 1 foot at UXO detonation locations are required to be removed.
5. MEC Removal to Maximum Depth of UXO or MD with MC Contaminated Soil Removal at UXO Detonation Locations: An MEC removal will be conducted to the maximum depth of the UXO or MD recovered from the specific MRS during the RI or previous investigations along with MC contaminated soil removal at UXO detonation locations.
6. Fencing and Signs: Installing fencing and signs around the site to restrict access and minimize possible receptor interaction.
7. Excavation, Sifting, and Restoration: Completely remove all MEC and munitions debris items from the site and restore it.
FIGURE 3.10
MEC/MD density map of the RA and RI/FS sites inside the former Camp Sibert. The blue lines are the boundaries of the RA or RI/FS project sites, also known as a munitions response site (MRS). The orange dashed line is the former Camp Sibert boundary. The dark red dashed lines are the boundaries of the estimated higher MEC and MD areas. The small black points are the MEC/MD locations. Red represents the highest MEC/MD density area, followed by pink, orange, yellow, and green, representing lower MEC/MD density areas. The MEC/MD density unit is density per acre.
FIGURE 3.11
An example MEC/MD density map of Site 18, which is a conventional Munitions and Explosives of Concern (MEC) impacted site. Similar MEC/MD density maps were generated for all the selected Removal Action (RA) and Remedial Investigation and Feasibility Study (RI/FS) sites inside the former Camp Sibert. The red line represents the boundary of the RA or RI/FS project site, also known as munitions response site (MRS). The orange dashed line is the former Camp Sibert boundary. Red dashed lines are the boundaries of the estimated higher MEC and MD areas. The small black points are the MEC/MD locations. Red represents the highest MEC/MD density area, followed by pink, purple, orange, yellow, and green, representing lower MEC/MD density areas. The MEC/MD density unit is density per acre.
Case Study 3.8: Chemical Concentration Analysis

During the 2009 chemical agent contaminated media RA and the RI/FS investigations at Site 2A of the former Camp Sibert, the contaminated soil was sampled for the presence and levels of contamination from chemical agents and agent breakdown products. As discussed earlier in this chapter, Site 2A was formerly used for chemical agent decontamination training between 1942 and 1945 during World War II. When the war ended in late 1945, the chemical training at Site 2A was terminated and excess chemical agents were poured into the mustard soakage pit. Many soil samples were taken from the mustard soakage pit, and arsenic was detected in all of the samples at concentrations ranging from 640 µg/kg up to 140,000 µg/kg. Arsenic in 20 of those samples exceeded the established background level of 7,659 µg/kg (~8 mg/kg). The highest detected arsenic concentration was in a floor sample (SB-35) collected at a depth of 4 feet, as shown in Table 3.1. It is an example small data table queried out from a chemical analytical results database for illustration purposes.

This example table contains valuable information about the arsenic contamination of the mustard soakage pit. However, by simply looking at the numbers in the table alone, it is hard to understand and visualize the whole contamination situation of the area both on the surface and underground. In order to visualize the spatial distribution of the arsenic concentrations, this data table was joined to the sampling locations GIS data layer to generate a tag map showing both sample locations on the ground surface and their associated arsenic analytical results at all the sampled depth intervals underground, as shown in Figure 3.12. A GIS program was written to query out the arsenic results of each sample location, sort the arsenic results based on their sampling intervals, and automatically create a mini data table (also called a tag) next to the sample location. For a site with many samples and large volumes of chemical analytical data, this automated mapping process saved not only the time taken to generate a large number of mini data tables (or tags), which is tedious and error-prone cartographic work, but also avoids the efforts to QA/QC (quality assurance/quality control) the chemical numbers inside the tags, because no possible human data entry errors are introduced in the automated data processing and mapping work flow. Therefore, only the source data tables in the database need to be reviewed and checked. If the source data tables in the database are correct and accurate, then all the GIS tag maps automatically generated from the data tables should be free of errors. When the source data tables are updated, the GIS tag maps are also automatically updated. Also, the GIS program can be modified to display other types of data or measurements onto maps. It significantly increases mapping efficiency and data quality and reduces data QA/QC time and effort.
### Table 3.1

An Example Small Portion of a Large Arsenic Concentration (mg/kg) Data Table Queried Out from a Master Database of the Mustard Soakage Pit inside Site 2A of the Former Camp Sibert

<table>
<thead>
<tr>
<th>Depth</th>
<th>SB 31</th>
<th>SB 32</th>
<th>SB 33</th>
<th>SB 34</th>
<th>SB 35</th>
<th>SB 36</th>
<th>SB 37</th>
<th>SB 38</th>
<th>SB 45</th>
<th>SB 46</th>
<th>SB 47</th>
<th>SB 48</th>
<th>SB 49</th>
<th>SB 50</th>
<th>SB 51</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–2</td>
<td>100</td>
<td>16</td>
<td>4.3</td>
<td>3.4</td>
<td>380</td>
<td>67</td>
<td>2.8</td>
<td>60</td>
<td>3.2</td>
<td>140</td>
<td>3.7</td>
<td>5.1</td>
<td>4.2</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>2–4</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>750</td>
<td>80</td>
<td>2.3</td>
<td>6.1</td>
<td>2.7</td>
<td>154</td>
<td>3.4</td>
<td>5.6</td>
<td>4.9</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>3–5</td>
<td>720</td>
<td>2.8</td>
<td>2</td>
<td>3</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
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<td></td>
</tr>
<tr>
<td>4–6</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>1500</td>
<td>1.9</td>
<td>3.1</td>
<td>10</td>
<td>1.4</td>
<td>3.3</td>
<td>16.1</td>
<td>5.1</td>
<td>73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5–7</td>
<td>n/a</td>
<td>n/a</td>
<td>3.6</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>6–8</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>150</td>
<td>2.7</td>
<td>2.1</td>
<td>50</td>
<td>1.5</td>
<td>2.3</td>
<td>4.9</td>
<td>2.8</td>
<td>37.6</td>
<td>9.5</td>
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</tr>
<tr>
<td>8–10</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>77</td>
<td>2.2</td>
<td>2.1</td>
<td>9.2</td>
<td>3.9</td>
<td>3.8</td>
<td>2.7</td>
<td>5</td>
<td>7.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10–12</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>93</td>
<td>1.9</td>
<td>1.5</td>
<td>4.1</td>
<td>1.9</td>
<td>2.5</td>
<td>3.6</td>
<td>3.3</td>
<td>3.4</td>
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<td></td>
</tr>
<tr>
<td>12–14</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>95</td>
<td>2.1</td>
<td>2.4</td>
<td>3.4</td>
<td>3</td>
<td>4.6</td>
<td>3</td>
<td>3.7</td>
<td>21.6</td>
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<td>320</td>
</tr>
<tr>
<td>14–16</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>33</td>
<td>2.6</td>
<td>2.5</td>
<td>18</td>
<td>1.8</td>
<td>2.2</td>
<td>33.8</td>
<td>2</td>
<td>6.3</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td>16–18</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>51</td>
<td>2</td>
<td>1.6</td>
<td>160</td>
<td>1.5</td>
<td>67</td>
<td>2.5</td>
<td>7.2</td>
<td>ND</td>
<td>3.4</td>
<td>3.2</td>
</tr>
<tr>
<td>18–20</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>3.2</td>
<td>n/a</td>
<td>2.3</td>
<td>8.2</td>
<td>1.7</td>
<td>11</td>
<td>1.545</td>
<td>2</td>
<td>2.6</td>
<td>3.8</td>
<td>1.3</td>
</tr>
</tbody>
</table>

**Note:** Many samples were collected from different sampling depths, ranging from 0 to 20 feet and analyzed.
1. Background is 7.8 mg/kg.
2. Bold concentrations are above background.
Arsenic analytical results tag map of the mustard soakage pit in Site 2A of the former Camp Sibert. The black line represents the mustard soakage pit boundary. The blue line represents an intrusive investigation trench. The red points represent soil boring/sampling locations. The black points are geoprobe locations. The green points represent Phase II soil sampling locations. A chemical analytical data table in a master database was joined to the sample GIS data layer to display both the spatial locations of the samples and their arsenic concentrations at different sampling depth intervals underground. The mini data tables (also known as tags) placed next the samples on this GIS map were generated automatically from the data in the master chemical database with a GIS program written for creating this type of mini table formatted special labels, also known as tags.
With this data tag map, as shown in Figure 3.12, it was much easier to see the arsenic concentrations geospatially rather than simply reading the data tables. However, with so many sampling depth intervals, it is still not easy to visualize arsenic concentration patterns at each internal depth and their relationships. To further help scientists and decision-makers to better understand the data and visualize site conditions, the arsenic concentration data from all the samples and at all depth intervals were statistically analyzed using GIS geospatial analysis techniques, based on Kriging, inverse distance weight, and other interpolation methods. The analyzed results were displayed as color-shaded concentration maps, one map for each depth interval. Figure 3.13 is an example color-shaded arsenic concentration contour map of sampling depth interval of 0–2 feet. Each contour map was carefully examined to ensure that the statistically analyzed results corresponded correctly and accurately with the actual data. If it did not, more statistical analysis experiments were performed with adjusted parameters and models until the

**FIGURE 3.13**
A color-shaded arsenic concentration (at 0–2 feet depth interval) contour map of the mustard soakage pit in Site 2A of the former Camp Sibert. The colored points are soil samples, labeled with their IDs (on top) and arsenic concentration values (on bottom). The bright red shaded areas represent soil with a higher arsenic concentration, while the light red shaded areas represent soil with a lower concentration level. The dark yellow squares represent the 10 x 10 feet intrusive investigation and soil removal grids. The boundary of the mustard soakage pit is represented by the pink line. The blue lines represent a trench excavated in the mustard soakage pit.
correct and accurate analytical results were achieved. With this type of color-
shaded concentration contour maps, it is much easier to understand the arse-
nic concentration patterns at all the depth levels from 0 (surface) to 20 feet
underground and estimate the soil volumes to be excavated and transported
to the processing facility.

These geospatial analysis and visualization techniques added values to
the existing datasets and revealed useful and meaningful information which
was hidden in the large amount of numbers and which made it hard to see
and understand. Three-dimensional modeling of the contaminated subsur-
face soil of this mustard soakage pit area will be discussed in more detail in
Chapter 5.

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**Case Study 3.9: Analyzing Groundwater Elevations and Flow Directions with GIS**

For an environmental project site with groundwater contaminations, inves-
tigation of its groundwater conditions, such as groundwater elevations and
its flow patterns, is required to understand the sources of the contaminants,
delineate a contaminated groundwater plume in 3D space, and predict its
potential changes and movements. Tracking of temporal changes in contam-
inant concentrations is critical for the assessment of contaminated ground-
water plume movement and its likely migration pathways and for designing
and refining groundwater extraction and treatment systems to capture and
remove the contaminants.

The formerly used Naval Air Station Brunswick (NASB) in the state
of Maine is such an environmentally impacted site with a contaminated
groundwater plume. The installation was originally constructed in 1943
mainly to train British Naval Command (Royal Canadian Air Force) pilots.
During World War II, the facility also performed a secondary role of support-
ing anti-submarine warfare. After the war ended in late 1945, the instal-
lation was deactivated in October 1946. In 1949, the former NASB was used
by the Brunswick Flying Service, a commercial aviation company. In 1951,
during the Cold War, the station was re-commissioned as a naval air facility,
mainly supporting three land-plane patrol squadrons, one fleet aircraft
service squadron and a planned future mission as a master jet base. In
December 1951, the naval a facility had its name officially changed to Naval
Air Station Brunswick (NASB). The U.S. Air Force also used the installation
for some missions from time to time. At the end of the Cold War in 1991,
many operations at the naval air station were either reduced or relocated. In
2005, the installation was added to the Base Realignment and Closure list
with a mandated closure date of September 2011. The former NASB site was
officially decommissioned on May 31, 2011.
Due to the past operations, especially ordnance and fuel-related activities in the formerly used NASB, the soil and groundwater were contaminated in many areas, also known as sites. Figure 3.14 is a GIS map showing the layout of the formerly used naval air station and the environmentally impacted sites inside it. The elongated yellow area on the east side of the NASB is the Eastern Plume site. The groundwater under it was contaminated by dissolved-phase volatile organic compounds (VOCs). It is the focus of this case study. Some of the sites shown in Figure 3.14 were the sources of the contaminants.

**FIGURE 3.14**
A GIS map showing environmentally impacted areas (also known as sites) in the formerly used Naval Air Station in Brunswick, Maine. The yellow elongated area is the Eastern Plume. The groundwater under it was contaminated by VOCs, forming a plume.
A long-term groundwater monitoring and sampling program was conducted from 1995 to the 2000s, with roughly two to four monitoring and sampling events per year. Long-term monitoring and sampling is widely used to assess the effectiveness of remedial approaches and monitor changes in contaminant concentrations in groundwater plumes over time. The primary goal of this monitoring and sampling network was to monitor the changing conditions within the sand groundwater aquifer impacted by dissolved-phase VOCs including TCE, PCE, 1,1,1-TCA, and DCE in groundwater. There was an operating pump and treat system at the site of the Eastern Plume to remove groundwater contaminants and maintain hydraulic control of the VOCs-contaminated plume. The results of the monitoring and sampling were used to assess and improve the groundwater extraction and treatment system to make it more effective in capturing and removing contaminants.

Groundwater measurements and sampling were conducted at over 40 monitoring wells during many sampling events over seven years, resulting in the generation of more than 250,000 data records of chemical analytical data and groundwater measurements. GIS spatial analysis techniques were used in processing and analyzing these massive data records to model the contaminated groundwater plume in 2D and 3D spaces and to interpret groundwater elevation contours and flowing directions for each sampling event. Figure 3.15 contains groundwater elevation contours and flowing directions in the Eastern Plume area. The colored lines are groundwater elevation contours statistically analyzed from the groundwater measurement data from the long-term monitoring and sampling events. The blue lines are the groundwater elevation contours of the shallow aquifer and the red lines are the contours of the deep groundwater aquifer. The arrows are the interpreted groundwater flow directions from the contours. With the groundwater elevation data from all the long-term monitoring and sampling events in one map, it is much easier to visualize and understand the patterns of the groundwater conditions of the site, their changing trend during the monitoring events, the relationship between the source sites and the Eastern Plume, and the potential movement of the contaminated groundwater plume.

From groundwater measurement data, GIS can generate groundwater elevation contours automatically using Kriging, IDW, and many other statistical interpolation theories and models. Depending on the quantity and quality of the data, analysis results could vary largely.

Therefore, as with other types of statistical analysis, groundwater elevation contours generated automatically by computer should be reviewed carefully to ensure that they match the data correctly and accurately. If not, more experiments should be conducted with different statistical analysis methods and parameters until reasonably accurate results are achieved. It might also be necessary to manually edit computer generated contour lines to make them match the data and real conditions more closely. In this case, the automatically generated groundwater elevation contours GIS files were converted
into AutoCAD drawings (in ‘.DXF’ or ‘.DWG’ format) for the knowledgeable geologists and environmental engineers to review and make edits. Then, the edited AutoCAD drawings were converted back into GIS data layers to be displayed and analyzed with other relevant datasets to investigate the sources of the groundwater contaminants, study the past and current sizes and conditions of the contaminated groundwater plume, model the plume’s future changes and movements, and evaluate and enhance the pumping and treatment system to achieve the remediation goals.

Three-dimensional modeling of this contaminated groundwater plume will be discussed in more detail in Chapter 5. Three-dimensional modeling and visualization techniques would further enhance the understanding of the VOCs-contaminated groundwater plume and provide the information to make effective remedial decisions.
Case Study 3.10: Virgin Islands National Park General Management Plan/Environmental Impact Statement

The U.S. Virgin Islands are a group of islands in the Caribbean, including the larger islands of Saint Croix, Saint John, and Saint Thomas and many surrounding minor islands (Figure 3.16), with a total land area of around 133.7 square miles. They are geographically part of the Virgin Islands archipelago and are located in the Leeward Islands of the Lesser Antilles, which separates the Caribbean Sea from the Atlantic Ocean. The territory’s capital is Charlotte Amalie on the island of Saint Thomas.

Virgin Islands National Park includes the majority of the island of St. John, as well as Hassel Island and Red Hook units on St. Thomas, with a total land area of approximately 7150 acres, as shown in Figure 3.17. Since the Virgin Islands National Park is mainly on St. John Island, the following discussion is focused on this portion of the park.

Virgin Islands National Park was established by Congress in December 1956 to administer and preserve the outstanding scenic and other features in...
The Virgin Islands National Park is a nationally and internationally significant tropical environment where the processes of nature can be observed and studied. Due to its internationally significant natural resources, the Virgin Islands National Park was designated as a Biosphere Reserve by the United Nations Educational, Scientific, and Cultural Organization in 1976. The park contains a variety of terrestrial and marine species. Among them are many threatened and/or endangered species, such as the piping plover, Kirtland’s warbler, roseate tern, green leatherback and hawksbill sea turtles, elkhorn and staghorn coral, the humpback whale, Thomas’ lidflower, and St. Thomas prickly ash.

The park is also rich in cultural resources, with a variety of archeological sites dating from as early as 840 BC to the arrival of Columbus in the 1490s. Throughout the park, there are many historic landscapes and architectural remains of hundreds of structures from plantation estates. There are numerous ruins in the park, including windmills, animal mills, factories, great houses, terrace walls, and warehouses. Some historic structures, ruins, and sites are listed on the National Register of Historic Places.

Due to the significant growth in tourism and permanent/seasonal residents in the past five decades, a significant amount of development and construction has happened in St. John and other areas. The purpose of the general management plan is to provide comprehensive guidance for perpetuating natural systems, preserving cultural resources and providing opportunities for quality visitor experiences at Virgin Island National Park. It establishes the management framework for the park, addresses changing issues and conditions, incorporates new resource information, and provides management direction for new park lands.

The main purpose of the environmental impact statement is to identify the range of potential natural and cultural resources and environmental elements that could be affected by the implementation of this general management plan. A variety of relevant impact topics are selected and analyzed in the environmental impact statement, in accordance with the Council on Environmental Quality guidelines for implementing the National Environmental Policy Act and NPS management policies. The impact topics retained for analysis are:

- Air quality
- Soils
- Water resources (water quality and watershed conditions)
- Wetlands (mangroves and saltponds)
- Floodplains
- Vegetation
- Wildlife (marine and other wildlife species)
- Fish and marine invertebrates
• Marine resources (coral reefs, seagrasses, other types of bottom habitats, open water and other essential fish habitats)
• Special status species
• Soundscapes
• Scenic resources
• Cultural resources (archaeological resources; historic structures, buildings and districts; cultural landscapes; ethnographic resources; collections and archival materials)
• Visitor use and experience (visitor use and access, recreational opportunity, and access to orientation information and interpretation)
• Socioeconomics
• Transportation
• Park operations and facilities (staffing, park facilities and maintenance, commercial services)
• Public health and safety
• Sustainability and long-term management

GIS technology was used extensively to collect and analyze a large amount of data in support of preparing the general management plan and the environmental impact statement. The datasets collected and analyzed include current and future land uses, real estate development, facilities, utilities, transportation, soil, wetlands, vegetation, water resources, habitats, cultural resources, census, and trails. Figure 3.18 shows the properties and subdivisions inside Virgin Islands National Park in St. John. There are many private lands and development inside the park. Figure 3.19 displays floodplains inside Virgin Islands National Park in St. John.

In order to better manage different areas of the park, four management zones were created, including the Visitor Contact and Operations Zone, the Recreation Zone, the Nature and Heritage Discovery Zone and the Resource Protection Zone, as shown in Figures 3.20 through 3.23. The focus of the Visitor Contact and Operations Zone is to provide access and support a wide variety of experiences and opportunities to obtain park information in a relatively developed setting. The Recreation Zone allows for a variety of experiences and opportunities including cultural and natural resource education with proximity to some facilities such as comfort stations, parking lots, and trails that provide access to areas where recreational opportunities are plentiful. The Nature and Heritage Discovery Zone represents areas that would provide access to and support a wide variety of educational opportunities to learn about the park’s natural features and interpret the cultural heritage of hundreds of nationally recognized prehistoric and historic sites. The Resource Protection Zone focuses on resource preservation, protection, and scientific research and encompasses the core of the International Biosphere Reserve.
FIGURE 3.18
Properties and subdivisions inside Virgin Islands National Park in St. John. The yellow line is the Virgin Islands National Park boundary.
FIGURE 3.19
Floodplains inside Virgin Islands National Park in St. John. Floodplain data were obtained from Federal Emergency Management Agency (FEMA). Flood Zone A, high flood risk areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of 30-year; Zone AE, high flood risk areas, similar to Zone A; Zone VE, high flood risk coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves and a 26% chance of flooding over the life of 30 years; Zone X, low flood risk areas, outside the 500-year flood and protected by levee from 100-year flood. The yellow line is the Virgin Islands National Park boundary.
FIGURE 3.20 Layout of Virgin Islands National Park in St. John, under Alternative A: the No Action Alternative.
FIGURE 3.21
Layout of Virgin Islands National Park in St. John, under Alternative B, the Preferred Alternative.
FIGURE 3.22
Layout of Virgin Islands National Park in St. John, under Alternative C.
Processing and Analyzing Data to Extract Useful Information

FIGURE 3.23
Layout of Virgin Islands National Park in St. John, under Alternative D.
After thoroughly collecting and analyzing the relevant data from the management zones and other areas, four alternatives were developed for managing visitor use and resources at Virgin Islands National Park, with each alternative providing a unique management approach. The alternatives were developed based on the park’s purpose and significance, legal mandates, public views, and information on visitor use and park resources. The four alternatives are Alternative A, Alternative B, Alternative C, and Alternative D. They are discussed in detail in the following.

**Alternative A**
This alternative is also named the No Action alternative, that is, continuing current park management practices into the future. This No Action alternative serves as a baseline to evaluate the effects of the other three alternatives. It is also helps to explain why changes proposed in other alternatives for the future management of the park are necessary. Under this alternative, management practices, policies, and park programs, including maintenance of existing moorings, law enforcement, research, and operational practices, would continue without major changes. No new zones would be created under this No Action alternative either. The park would continue to be managed in accordance with the 1983 General Management Plan zones, as shown in Figure 3.20. They include the Natural Zone with Reef Subzone and Land Subzone, the Park Development Zone with Recreational Development Subzone, Access and Circulation Subzone, Administrative Development Subzone, a Residential Development Subzone, and the Historic Zone that includes key historic sites in the park.

**Alternative B**
Alternative B is the National Park Service Preferred Alternative. It was developed to address specific issues and concerns identified during the scoping process. The issues and concerns include

I. Improving communication of scientific study results with the public through strategic, sustained, long-term, expanded education, outreach, and partnering efforts
II. Adding new staff members to provide more consistent levels of education and enforcement activities
III. Providing increased protection of natural resources by phasing out anchoring over the life of the 15–20 year planning period and providing approximately 15–23 new moorings
IV. Implementing limited improvements of facilities and transportation systems and improving maintenance of facilities and historic resources
V. Applying adaptive management techniques for natural and cultural resources

VI. Implementing increased efforts to identify, stabilize, restore, and protect cultural resources

Compared with Alternative A (the No Action alternative), Alternative B enhances protective measures, education and visitor experiences at the park by establishing new management zones, which include the Resource Protection Zone, the Nature and Heritage Discovery Zone, the Visitor Contact and Operations Zone and the Recreation Zone, as illustrated in Figure 3.21. It also increases research, monitoring, enforcement, education, and partnering efforts.

Some new facilities are also proposed. They would be built using sustainable building practices in accordance with NPS policies and procedures to minimize footprints and disturbance of park resources. The NPS would participate in efforts to develop a jointly operated Museum/Environmental Heritage Center in Cruz Bay to provide a community center for cultural events, other special events, educational programs, and other activities.

Alternative C and Alternative D are similar to Alternative B, with only minor changes in the four management zones (i.e., Resource Protection Zone, Nature and Heritage Discovery Zone, Visitor Contact and Operations Zone and Recreation Zone), as shown in Figures 3.22 and 3.23 and other different management approaches and initiatives.

Executive Order 12898 requires all federal agencies to incorporate environmental justice into their missions by identifying and addressing disproportionately high and adverse human health or environmental effects of their programs and policies on minorities and low-income populations and communities. In compliance with this Executive Order and the National Environmental Policy Act, the proposed alternatives (A, B, C and D) were assessed during the planning process. It was determined that none of these four alternatives would result in disproportionately high, direct or indirect adverse effects on any minority or low-income populations or communities by analyzing the following information:

- The developments and actions in the alternatives would not result in any identifiable human health effects. Therefore, there would be no direct or indirect effects on human health within any minority or low-income population or community.
- The impacts on the natural and physical environment that would occur due to any of the alternatives would not disproportionately adversely affect any minority or low-income population or community, or be specific to such populations or communities.
- Impacts on the socioeconomic environment due to the implementation of actions proposed in the alternatives would be minor or
positive, and such impacts would not be expected to substantially alter the physical and social structure of nearby communities in St. John.

- The management alternatives would not cause hazardous materials to be generated or to affect the treatment of current hazardous materials.

All future development projects are subject to compliance with the National Environmental Policy Act, the National Historic Preservation Act, and other appropriate laws and regulations. Future project environmental reviews will be site specific and address natural and cultural resources, visitor experiences, and park operations.