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METHODOLOGY FOR DETERMINING REMAINING LANDFILL CAPACITY

To All Local Enforcement Agencies

The purpose of this advisory is to provide guidance and information that will assist in the selection of a method to determine the remaining capacity of a landfill. Also, the methods discussed in this advisory can be useful in determining past and current landfill volumes.

Public Resources Code, Division 30, Chapter 4, Article 1, Section 41701 was enacted into law to ensure that each county has planned for adequate safe disposal capacity for a minimum of 15 years. If a county determines that existing capacity will be exhausted within 15 years, then an area or areas for the location of new solid waste disposal facilities, or existing facilities that will be expanded, must be identified.

The determination of current and remaining capacities at solid waste landfills is a critical aspect of site operations for owners/operators and local enforcement agencies (LEA). Filling patterns, operational activities, and personnel and equipment planning can be aided by calculation of the remaining capacity at a landfill.

State, regional, and local planners also need and utilize accurate information concerning remaining capacity in planning for future development to ensure that adequate landfill space is available.

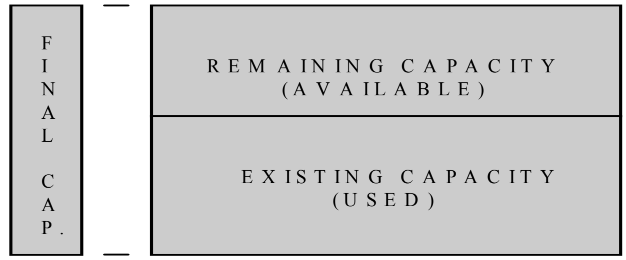
Background

The California Integrated Waste Management Board (CIWMB) authorized a survey to determine California's remaining landfill capacity and the methods used to determine those capacities. Approximately 250 landfills were surveyed during 1993 and 1994. Accurate calculations of remaining landfill capacity are critical to State, regional, and local planners in the development and placement of landfills in California. A report entitled *Determining Remaining Permitted Capacity of California's Sanitary Landfills* was the result of that survey and was accepted by the CIWMB at its May 1995 meeting. It is suggested that this report be reviewed in conjunction with this advisory. It can be obtained from the following sources:

- Call the CIWMB's hotline (1-800-553-2962) for a hard copy or a 3.5" disk (Word 6.0).
- Download from the CIWMB's home page (http://www.ciwmb.ca.gov). Choose Publications, then CIWMB Publications Catalog. The report is listed under Solid Waste Facilities and Operations.

Considerations For Determining Remaining Landfill Capacity

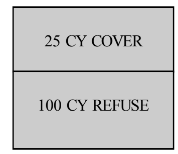
The following sections provide information to assist in understanding the concepts and terminology of landfill capacity and topographical maps.



What Is Remaining Landfill Capacity?

Determination of the remaining capacity of a landfill using topographical methods involves knowing the current and final configuration of the currently permitted landfill. The current and final configuration of the landfill is used to determine the current and final volumes. The remaining capacity is calculated by subtracting the current volume used from the final volume (*final capacity - existing capacity = remaining capacity*).

What Is a Refuse-to-Cover Ratio?



A refuse-to-cover ratio is the volume of daily or intermediate cover material that is placed over a volume of refuse. For example, if 100 cubic yards (CY) of refuse were disposed and 25 CY of cover material were used to cover the refuse; the refuse-to-cover ratio would be 4:1. This ratio must be determined on a site-specific basis as it is operation dependent.

Numerous landfills throughout California use alternative daily cover (ADC) due to the lack of available cover materials for diversion or in an effort to save space for landfilling. The proper use of an ADC may significantly reduce the need for daily cover and subsequently change the refuse-to-cover ratio.

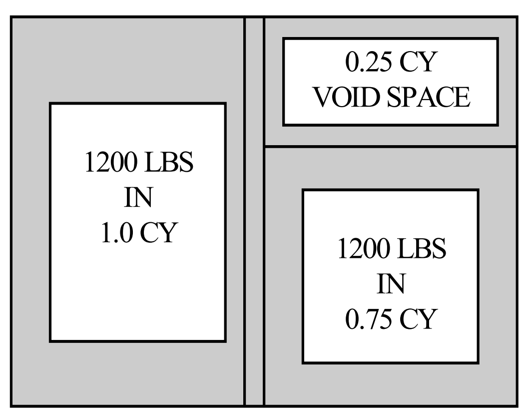
What Is Settlement?

Settlement in landfills is usually the result of consolidation of in-place refuse. Consolidation occurs when initial void (air) spaces in the refuse are replaced with surrounding waste and can be the result of additional refuse placement and/or the decomposition of the existing waste. Settlement is usually a process that occurs over time and is difficult to notice on a day-by-day basis.

In a few instances, settlement can occur as a result of an earthquake or consolidation of materials (soft soil base) located below the landfill.

Settlement rates vary with the type of refuse placed, operational techniques (compaction effort and equipment), as well as climatic conditions (dry vs. moist). The settlement rate of a landfill varies with time.

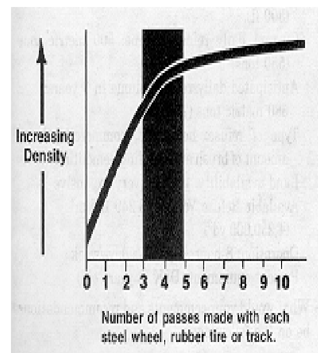
Typically, primary settlement occurs within the first few years (one to three) of refuse placement and long term settlement occurs over an extended period of time (four-plus years). There is no definitive study indicating the length of time or the maximum amount of settlement that is expected to occur; however, one study indicated that as much as 30 percent (of landfill height) settlement may occur after waste disposal ceases.



The gradual action of landfill settlement can have the effect of increasing landfill space over time. As an example, 1200 pounds of refuse may occupy 1.0 CY in a landfill when placed. Consolidation of that 1200 pounds of refuse may decrease the space occupied by 25 percent to 0.75 CY. That could mean an additional 25 percent of space for refuse placement. It is estimated that settlement at a landfill varies from 10 to 40 percent (of landfill height). Final settlement percentages are site specific and depend on the type of waste placed and the construction technique used.

Settlement can be minimized by greater compaction effort (increasing compaction equipment weight or additional passes with existing equipment) during the placement of waste. The additional action forces more waste into a smaller area. The decision to use heavier equipment or more passes with existing equipment is not only a settlement issue; it is also an economic one. The settlement process can also be increased by surcharging. Surcharging is the placing of additional weight (e.g. stockpiled soil) on top of a specific area to induce consolidation or settlement.

The graph to the right displays the relationship between the number of passes that compaction equipment makes and the increasing density. Note that after about five passes with the compaction equipment, the increased density per pass decreases. This graph is typical only and individual equipment will provide individual results. (Reprinted from the *Caterpillar Performance Handbook, 22nd Edition*, October 1991.)



What Is the Importance of Map Scale and Accuracy?

Scaling of the map is an important decision relating directly to both reading and using the information on the map. The scale of the map should reflect consideration of the purpose, size, accuracy, and required precision of the finished topographical map.

In general, topographical maps are developed using one of the following scales:

- 1" = 200' with a two-foot contour, and one-foot accuracy.
- 1" = 100' with a two-foot contour; and one-foot accuracy.
- 1" = 40' with a one-foot contour, and one-half-foot accuracy.

Accuracy of a topographical map is usually one-half of the contour interval; therefore, if the contour interval is two feet then the accuracy of points on the map are within one foot. The accuracy of a topographical map applies to specific elevations marked on the map such as targets, building corners or cross-hair locations (+).

The method chosen to calculate the remaining landfill capacity may help determine the appropriate map scale. Computer-generated programs that determine capacity do not require scaling because the topographic information is taken directly from the original data file. However, the use of a manual method for determining remaining landfill capacity will require a topographical map that is clear and readable. For example, a 150-acre landfill that is approximately equal in width and length should fit well on a D (24" X 36") size drawing at a scale of 1" = 200' with a two-foot contour and one-foot accuracy.

What Are Control Points?

Control points are locations where the elevation as well as location (northing and easting) are known to an exact specification. These locations and the accuracy they provide enable a ground or aerial survey to be accurately completed. The terms northing and easting are used to locate a specific point on a plane from a predetermined location. The predetermined locations have been chosen by the United States Geologic Survey (USGS). For example, a survey marker may be located by describing its location as 1,101,357 feet north and 357,687 feet east of a known location. West and south can also be used.

Horizontal control is provided by two or more points, precisely fixed in position horizontally by distance and direction. Vertical control is provided by benchmarks in or near the tract to be surveyed. These controls become the foundation for correctly portraying relief on a map. The actual number of control points should be determined by consultation with survey professionals.

What Are Contour Lines?

A contour line is a line connecting points of equal elevation. The contour interval selected depends on a map's purpose, scale, and diversity of relief in the area. The smaller the difference between contour lines, the more costly the final product, partly due to increased field work.

What Are Benchmarks?

Benchmarks are usually small metal plates marked with information and placed in concrete, usually on the ground. Benchmarks can either be permanent, for repeated use, or temporary, for one project use and then destroyed. Whenever possible, benchmarks are placed in accessible locations for reuse and kept safe from damage. All surveying must be completed and adjusted to known permanent benchmarks, including designating an elevation and location (northing and easting). These benchmarks are usually located throughout most counties for easy reference. An experienced surveyor should either have access to the benchmark locations or know how to obtain the information.

Methods for Determining Remaining Landfill Capacity

Based on the survey, the three most commonly used methods in the State of California for the determination of remaining capacity are:

- Topographical Survey Methods
- Weight-Based Methods
- Trench-Based Methods

Note that for the purposes of this advisory, current in-place volume and total and remaining capacity will be discussed in terms of cubic yards (CY), because the volume capacity of a landfill (in CYs) is a constant. Because the in-place density of a waste is highly variable, a discussion of landfill capacity in terms of tonnage would be misleading. Reports from landfills in California have reported in-place densities ranging from approximately 1000 to 1600 lbs/CY.

Topographical Survey Methods

Topographical mapping is the process of graphically representing natural and man-made features for a given locality and for the determination of the configuration of the terrain on a map. Topographical maps are the most widely used form of representation of landfills in California.

By means of various lines and conventional symbols, topographic maps are produced from survey data. Names, legends, and various lines are used to identify features such as roads, trees, streams, lakes, trails, buildings, and boundary lines on the map.

Topographical surveys have been shown to be a valuable tool for accurately determining volumetric quantities for landfills. Depending on the need and the information available, the volumetric quantities can be for the past, current, or the final volume for a landfill.

Topographical maps can be developed using ground or aerial surveys. The decision as to which survey would be appropriate is based on site-specific considerations such as landfill size, availability of a survey crew, and total costs.

The use of topographical methods combined with weight-based disposal data provide an added benefit of determining the density (weight/volume) ratio for disposed waste.

The use of daily and intermediate cover requires airspace in the landfill. Therefore, the ratio of refuse to cover material must be determined so an accurate estimate of remaining airspace may be calculated.

The following two sections will discuss the ground survey and photogrammetric methods of preparing a topographical map.

What Is a Ground Survey?

A ground survey is conducted using a ground crew to develop a topographic map representing the existing terrain. Ground surveys are usable in essentially all situations where topographic or boundary data is needed for landfill operations. Considerations for using the ground survey method should include, but not be limited to, the size of landfill, availability of personnel, and total costs.

Ground surveys are most likely to be cost-effective for smaller landfills, usually about 10 acres or less. The use of ground surveys for smaller landfills is usually less expensive than aerial surveys due to the cost of setting up control points (targets) and initial startup fees (airplane and initial calculations) required for use with aerial surveys.

The availability of a survey crew to perform the work during a given time period may be an issue for some landfills. Heavy construction periods or development may limit the availability of a survey crew to perform the work.

Total cost for a ground survey should be considered. The component costs at a minimum may include a site visit, pre-field office preparation, actual field work, and map preparation and duplication.

In some cases only localized topographical surveys may be required at a larger landfill. For instance, if only a small area has changed due to localized filling it may not be necessary to obtain a topographical map of the entire site; therefore, a ground survey may be appropriate.

How to Choose a Land Surveyor

Licensing and Sign-off. Professional land surveyors in California are licensed and regulated by the State Board of Registration for Professional Engineers and Land Surveyors (BORPELS) as specified in the Professional Land Surveyors Act. Confirmation of the status of a surveyor's California license and any disciplinary actions can be obtained by contacting BORPELS in Sacramento, California, at (916) 263-2222 or (916) 263-2233.

Only a licensed land surveyor or an eligible civil engineer may set or determine property boundary lines within the State of California. Therefore, any surveying that is submitted or completed that requires the determination of property boundary lines will require one of the above individuals to perform or directly supervise and sign off on the submitted survey. Certain maps are required by regulations to be signed by a Registered Civil Engineer or Certified Engineering Geologist, such as maps depicting the final grade or drainage designs of landfills.

Please note that not all documents prepared require the seal and signature of a registered land surveyor or civil engineer. Some information may be obtained and used for in-house or submittal purposes by knowledgeable individuals. Examples of map submittals that would not require a signature and seal include vicinity maps and/or site maps.

Experience/References. Experience with the required tasks should be considered when selecting a surveyor. Time and types of surveying completed by the selected contractor are also important considerations. A land surveyor that is relatively new to topographical work on a large scale and who has only completed work on small subdivisions in the past may require additional time and assistance to prepare a landfill topographical map.

Due to the importance of accurate information for purposes of planning and landfill site operations, experience with the work to be performed will save time and money and produce a better product. Actual work on landfills may not be necessary; however, experience with the production of topographical maps is suggested. It is always a good practice to check the references of any contractor who will be used for the first time. A review of previous topographical maps prepared by the surveyor would provide information on the quality of the work produced.

Insurance. Proof of insurance of a contractor should also be considered when preparing a contract for services. Engineers and land surveyors normally carry errors and omissions insurance as well as liability insurance and a performance bond.

What Is an Aerial (Photogrammetric) Survey?

Photogrammetry is the science of making measurements and preparing maps from aerial photographs. The process of aerial photogrammetry includes the operations, processes, and products involving the use of aerial photographs. Included among these are the measurement of horizontal distances, the determination of elevations, the compilation of planimetric and topographic maps, the measurement of profiles and cross-sections, and the interpretation and analysis of aerial photographs for engineering investigations.

How Is It Done?

Aerial photogrammetry uses stereo pairs of photographs to interpret the selected area. The use of an aircraft to take the pictures requires good visibility and favorable wind conditions for a successful flight. Cloud cover, rain, or windy conditions can prohibit the flight for aerial photogrammetry.

Office preparation and coordination of information between the ground and aerial survey companies are essential parts of developing a flight plan for the survey.

The aerial photographs are analyzed using previously placed ground control points. These control points enable the determination of elevations (contour lines) and horizontal distances within the designated area. The control points are set by qualified land surveyors at exact elevations and locations. The number and size of control points necessary is determined by the aerial surveyor after consideration of the size and configuration of the landfill. Most control points are placed slightly outside the perimeter of the landfill and, if necessary, on the landfill itself to confirm elevations and locations. The target information is then given to the individual interpreting the aerial photograph and is used in developing the topographical map.

Optimum Conditions

The taking of an aerial photograph used to develop a topographical map requires favorable weather conditions. The sun must be greater than a 30-degree angle from the horizon and the sky must be clear of clouds and the land of fog. Because of the reduced shadows, noon is the optimum time for an aerial photograph for developing a topographical map.

Costs

Due to the high cost of pre flight preparation, the airplane, the flight crew, and the photo interpretation, the flight for the aerial survey may be more expensive than using a ground survey crew for the site.

Timeline

Once the aerial photograph has been taken, the time necessary to prepare the topographical map can vary from as little as two weeks to as long as three months, depending on the amount of detail required and the aerial firm's workload.

How to Choose an Aerial Surveyor

Licensing and Sign-off. At this time the State of California does not have a licensing requirement for aerial surveying; however, licensed land surveyors or engineers can be aerial surveyors. To ensure that the map produced is accurate, a land surveyor can work in conjunction with the aerial surveyor and sign off on the accuracy of the produced map. It would be beneficial for someone using an aerial firm to ask about standards and quality control of the process used. Experience in flight preparation, project planning, and aerial photography interpretations are critical in preparation of an accurate topographical map.

Aerial/Ground Survey Cooperation. An important issue when choosing an aerial surveying firm is the consideration of the ground survey and the aerial survey firm cooperation. For a topographical survey to be valid and usable, information from the ground survey must be given to the aerial firm for use in interpretation of the photographs used to produce the topographical maps. The aerial survey firm must work with the ground survey firm in determining the number, size, and placement of the ground control points (targets).

Planning/Climate Considerations. Planning for an aerial survey needs to include the availability of the crew and airplane. The number of firms performing aerial surveys within the state are limited and their flight time is restricted by climatic conditions. It is not unusual for an aerial firm to propose a flight date for the photograph and have to postpone due to cloud cover reducing the visibility or excessive winds prohibiting the straight line flight required to take the photographs.

Experience/References/Insurance. Experience with the required tasks should be considered when selecting an aerial surveyor. Time and types of surveying completed by the selected contractor are important considerations. Due to the importance of accurate information for purposes of planning and landfill site operations, experience with the work to be performed will save time and money and produce a better product. Actual work on landfills may not be necessary; however, experience with the production of topographical maps is suggested.

It is always a good practice to check references on any aerial surveying contractor that will be used for the first time. A review of previous topographical maps prepared by the surveyor would provide information on the quality of the work produced.

Proof of insurance of a contractor should also be considered when preparing a contract for services.

Comparison of Topographical Methods

In some cases the choice between the use of aerial or ground survey will be difficult. A comparison of aerial and ground survey methods is displayed on the attached table (Attachment A).

The following information should be considered when choosing between the ground survey and aerial methods of preparing a topographical map.

Ground surveys with manual data development and calculations are likely to be advantageous under the following parameters:

- A competent workforce is available at internal rates, such as company or county surveying crews.
- Area to be surveyed is less than 10 acres, or data collection needs are relatively small.
- Site topography is not so variable as to overly restrict foot-access to survey points.
- Survey, mapping, measuring, and/or computing equipment is available economically.
- Aerial survey vendors are not readily available.
- The combined time window for ground visibility and seasonal weather changes are too narrow to schedule aerial photography reliably.
- Cover soil management or other site operations considerations require closer (more frequent) fill rate monitoring than is practical with aerial photography.
- Waste flow quantities are small resulting in only minor topographic changes.
- Data are needed before the aerial photography process can be completed.

Aerial surveys are likely to be advantageous if the following parameters apply:

- Internal field workforces are not readily available.
- Site size and/or data collection needs are substantial.
- Site topography allows placement of ground control target points, but otherwise makes ground survey of the site impractical.
- Aerial survey vendors are available and affordable.
- The seasonal time window, if applicable, is adequate for aerial photography.
- Adequate lead-time is available for completing the automated process.
- Automated photography, mapping, and/or computing equipment is available economically.
- Skilled mapping, data extraction, and computational staff or contractors are available and affordable.

To avoid confusion, additional costs, and delays, a draft copy of the topographical map should be reviewed by knowledgeable landfill personnel prior to producing the final map to assure that all appropriate information is included and that it is accurate.

Calculating Capacities Using Topographical Maps

Once a topographical map has been prepared using either the ground survey or aerial survey method, the calculation of remaining capacities can be completed by using either automated or manual techniques. The method chosen depends on the resources available and the desired outcome. Consistency in using a calculation from one time to the next is important to insure information is as accurate as possible.

Electronic Calculation

For a computer to be able to calculate landfill capacity, the information must be in a computer file that is compatible with the program used to perform the necessary calculations. Computer-aided design (CAD) programs can use appropriate ASCII files to determine remaining landfill capacity. The computer hardware needs for these calculations depend on the program's requirement. For instance, certain versions of CAD programs require minimum RAM for operation.

Manual Calculation

The "average end method" of determining volumes can be used manually to determine remaining capacity from computer-created maps as well as manually drawn topographical maps. This method can be used with either vertical or horizontal cross sections of the landfill. A cross section area (square feet) is determined and then averaged with an adjacent cross section area. The average area is then multiplied by the distance between the two cross sections producing a volume in cubic feet. The distance between cross sections can be from 10 to 100 feet depending on the number of cross sections that must be completed. The volume of the area between the two cross-sections is then divided by 27 to convert the cubic feet number to a cubic yard (27 cubic feet = 1 cubic yard). Attachment B provides an example of the average-end method. The volumes between all the cross sections will be added together to give a total volume of the area represented by the topographical map. The manual method is labor intensive and requires both experience and the ability to perform repetitive calculations accurately. Experience of the technician using the manual method is very important.

How Often Should Topographical Maps Be Prepared for Volume Calculations?

Site-specific conditions should be considered when determining the frequency of topographical map production. The map can be used for determination of remaining capacity; however, it can also be used as a valuable tool to ensure that compaction efforts are producing the density/volume ratios expected and in preparing future filling plans. It may be necessary to produce a topographical map on an annual basis:

- For sites that are nearing completion.
- For sites that require available space data for planning.
- As a tool to assure that compaction techniques are obtaining the desired results.

A rural landfill that receives minimal waste volumes may require a new topographical map every five years. A larger, more active landfill may need a topographical map prepared annually or partial updates more frequently. This map can then be used to update the information in the report of disposal site information and the solid waste facility permit.

One advantage of using periodic topographic surveys to assess remaining capacity is that the method provides a cross-check for determining in-place density of refuse.

Weight-Based Methods

Weight-based estimates for determining landfill capacity convert weight data to volume using an assumption about the in-fill density of waste materials. The converted volume of material is subtracted from the total available airspace (capacity). This method requires no special expertise beyond careful record keeping and conducting basic mathematical calculations, using a scale for weighing the amount of waste received, and a scientific calculator or computer spreadsheet program.

Disadvantages

This method is generally not as accurate due to inherent problems:

- There are a relatively large number of assumptions, such as density, refuse-to-cover ratio, and settlement used in the calculations, and an error in assumption can compound into significant inaccuracies.
- There are no built-in cross-checks in the method.
- The amount of daily and intermediate cover used must be carefully taken into account.
- Many small landfills lack scales.

Applicability

This method relies entirely on assumptions about density and refuse-to-cover ratios, with infrequent or no cross-checks using topographic surveys. Although this method is less accurate, because of the relative ease and low cost, it is recommended for smaller-area landfills receiving less than 10 tons per day or slightly larger tonnage at landfills with a large amount of remaining capacity. It is suggested that an occasional topographical survey be performed to provide a more accurate update of the benchmark capacity.

Variation

A variation on the weight-to-volume conversion method is the in-truck volume to landfilled volume conversion method. This method, which can be used by landfill operators who do not have a truck scale, involves measuring the volume of materials in trucks arriving at the facility, making assumptions about the density of these materials, and calculating the weight of the materials. As an example, the density of waste that has been collected in an open truck will be significantly less than the waste that was picked up by a collection truck with a hydraulic compaction system. It should be noted that packer collection trucks (trucks that pack refuse in their storage area) vary in the density that they may obtain, due the effort by trucks hydraulic system. The greater the waste density upon receipt, the less compaction effort will have to be used for placement in the landfill.

The landfill operator then calculates or estimates the density of landfilled material and refuse-to-cover ratios to derive an estimate of the amount of landfill space used. This method requires tracking incoming loads by truck type, size, and fullness, then using density assumptions and a simple spreadsheet to convert volume to weight. Like the weight-to-volume method, this method also involves estimating or calculating refuse-to-cover ratios and taking into consideration design features and other contingencies.

Calculating remaining capacity using the weight-based method may take from several hours to several days depending on the following factors:

- The size of the landfill.
- The time since the last topographical survey was done.
- The completeness of records of in-coming material.
- Daily and intermediate cover usage.
- Basic operating parameters (such as weight of equipment, average number of passes, depth of spread material, slope of working face).

If an assessment of remaining capacity has not been performed for a number of years, then operators can assume that they will spend considerable time and effort the first time this method is employed. Subsequent annual updates should be relatively simple and quick, particularly if operating parameters and the character of the waste stream do not change significantly and if records are complete and accurate.

Trench-Based Methods

Determination of remaining landfill capacity using trench-based calculations requires minimal information that can easily be gathered in the field or from previous construction notes and future design specifications. Landfills that use a trench disposal method can easily determine remaining capacity with simple field observations and basic mathematical calculations, as long as the dimensions of the trenches can be accurately determined.

The accuracy of those remaining capacity calculations will depend on the reliability of the information used. Determining remaining capacity of a trench-type fill involves measuring the length, width, and depth of each existing and planned trench to assess the volume of each. Site life, density of landfilled material, and refuse-to-cover ratio can all be calculated by measuring the length of trench used, the weight of incoming material, and the volume of cover material used. This method allows for cross-checking of remaining capacity by monitoring the rate of fill over time.

For instance, an operator of a landfill with a constant waste stream calculates that it takes approximately one year to fill a trench with known dimensions. If the operator has enough space left for 15 similar trenches and the waste stream is not expected to change, then it can be estimated that the site has approximately 15 years of capacity remaining.

Selection of Method to Be Used

The selection of a method to be used to determine the remaining capacity of a landfill is a site-specific decision. Site-specific information should include information on site history, economics, local and State planning, as well as a combination of present and future needs, available resources, and type of operation and equipment available.

Table 1, "Comparison of Recommended Methods for Determining Remaining Capacity," from the report *Determining Remaining Permitted Capacity of California's Sanitary Landfills,* is attached (Attachment A) and provides an overview of the costs, accuracy, landfill type, size of landfill, and equipment/experience required for use of the various methods listed in this advisory.

Trench-Based Method

Appropriate Use

A trench-based landfill (typically small) that has historically used the trench-based method to determine remaining capacity may wish to continue with that method, providing past calculations have been shown to be accurate. If a single trench was estimated to take six months to fill and actually took six months to fill, then the trench-based method may be adequate for that site's needs. Additionally, for those trench-based disposal sites that want more accurate information or where past calculations have shown inaccuracies, additional steps to determine density may improve the remaining capacity data. Those additional steps could include determining the weight of the refuse by use of a scale or estimating the weight by volume of the refuse prior to placement. The trench-based method is the least expensive of the three discussed in this advisory for determining remaining landfill capacity.

Cost

Costs for determining the remaining capacity of a trench-based landfill are relatively minor in comparison to both weight-based and topographical methods. Measurement of the trench and accurate notes as to the time necessary to fill the trench are the minimum requirements needed. With a few simple calculations, the remaining capacity can be estimated. It is reasonable to assume that this method could be completed within one day of staff time.

Weight-Based Method

Appropriate Use

Weight-based landfill calculations provide a remaining capacity calculation that is dependent on the accuracy of the assumptions used. Without extensive record keeping or repetitive calculations to determine density and refuse-to-cover ratios, the remaining capacity may not be as accurate as expected or necessary and appropriate. In addition, the use of topographical maps for determining the remaining volume coupled with the density information will increase the accuracy of this method. However, the addition of a topographical map to the weight-based method will significantly increase the cost. The topographical map that would need to be completed for this type of evaluation would not be as extensive as one that would need to be prepared for the topographic map method.

Cost

The cost for determining the remaining landfill capacity using the weight-based method is directly related to the method used for collecting the weight information and calculating the capacity. The collection of accurate data is vital to this method for determining the remaining capacity. If the weight data is collected by a scale and computer system, the amount of staff time will be minimized. If the weight data is collected and recorded by hand then staff time will increase. The calculation time and costs will also be determined by whether a computer spreadsheet or program is used versus staff performing the calculations by hand.

Topographical Survey Method

Appropriate Use

Topographical maps are considered the most accurate method for determining remaining capacity. A topographical map can be produced using either the ground survey or aerial methods. The selection of the type of method to use is again a site-specific consideration taking into account resources, need, timing and costs.

Cost

Surveying costs usually include time for preparation, the field survey, and preparation of the map. All three functions are equally important with regard to accuracy and cost. Costs should be estimated for these three functions.

To enable a surveyor to prepare and give an accurate cost estimate, the following information should be provided when requesting services:

- Area to be covered (outlined map).
- The topographical map scale (1"=100', 1"=40', etc.) needed.
- Accuracy and contour interval.
- Due date.
- Type of product needed (reproducible mylars, blue lines, additional contact prints, photographs from aerial, etc.).

For long-term cost savings it may be appropriate to have a permanent benchmark (permanent mark with exact location known) placed on stable native ground near the landfill. The placement of a known location would increase costs initially; however, it could save resources and money in the long run. It is important that if a benchmark is placed it be well documented and protected from being disturbed or damaged.

To keep costs of conducting occasional surveys to a minimum, landfill operators may be able to use existing equipment and expertise (e.g., having county road surveying crews conduct a ground survey), and use in-house expertise to perform volume calculations. The cost of conducting aerial surveys can be minimized if the photogrammetry of the landfill is conducted as an add-on to another aerial survey in the area; or, if off-the-shelf, commercial aerials are available. If no topographic survey has ever been performed on the fill, there will be the additional expense of digitizing the final contours or conducting manual area and volume calculations of the remaining planned lifts. These steps need not be repeated each time the topographic survey is conducted unless design parameters change in the interim.

If you have any questions concerning this advisory please call Darryl L. Petker, P.E. of the Remediation, Closure, and Technical Services Branch at (916) 341-6704 .

Sincerely,

Dorothy Rice, Deputy Director
Permitting and Enforcement Division

Attachments
Back copies of LEA Advisories can be obtained by calling the LEA Support Services Section at (916) 341-6308 or at http:\\www.ciwmb.ca.gov.

ATTACHMENT A

Table 1: Comparison of Recommended Methods for Determining Remaining Capacity

Method	Cost	Accuracy	Type of Landfill	Size of Landfill	Equipment/ Expertise Required
Aerial Surveys with Computer-assisted Calculations	Generally highest cost, though may be less expensive than ground surveys for larger (over 10 acres) landfills.	Highest level of accuracy, with built-in cross checks. Should be accurate to within 10%.	All types of area landfills.	Appropriate for landfills over 10 acres.	Airplane, photogram-metry equipment, stereo plotter, autocad with add-on; operators for all of this equipment.
Ground Surveys with Manual Calculations	Middle cost; cost is generally less than aerial surveys for sites under 10 acres.	Depending on expertise and care of surveyors, map-makers, and whoever performs calculations, 10-20% accuracy.	Appropriate for all area-type landfills.	Best for landfills under 10 acres, or for larger landfills if it can be accomplished in-house at lower cost.	Manual surveying equipment, drafting equipment, planimeter or grid paper, calculator or computer spreadsheet; operators for all of this equipment.
Weight-Based	Low cost, particularly after first use of this method.	Accuracy of 20-25 percent is possible.	Appropriate for area-type landfills.	Appropriate for smaller and low-volume landfills.	Calculator or computer spreadsheet, accurate records of incoming material in volume or weight; care in performing calculations.
Trench Volume	Very low cost.	Accurate to within five percent.	Trench-type landfills with consistent trench dimensions, and area-type landfills with consistent cell dimensions.	Any size.	Calculator or computer spreadsheet; ability to perform basic geometric calculations.

* Table 1 is reproduced from the report entitled *Determining Remaining Permitted Capacity of California's Sanitary Landfills* (Table 2, page 15)

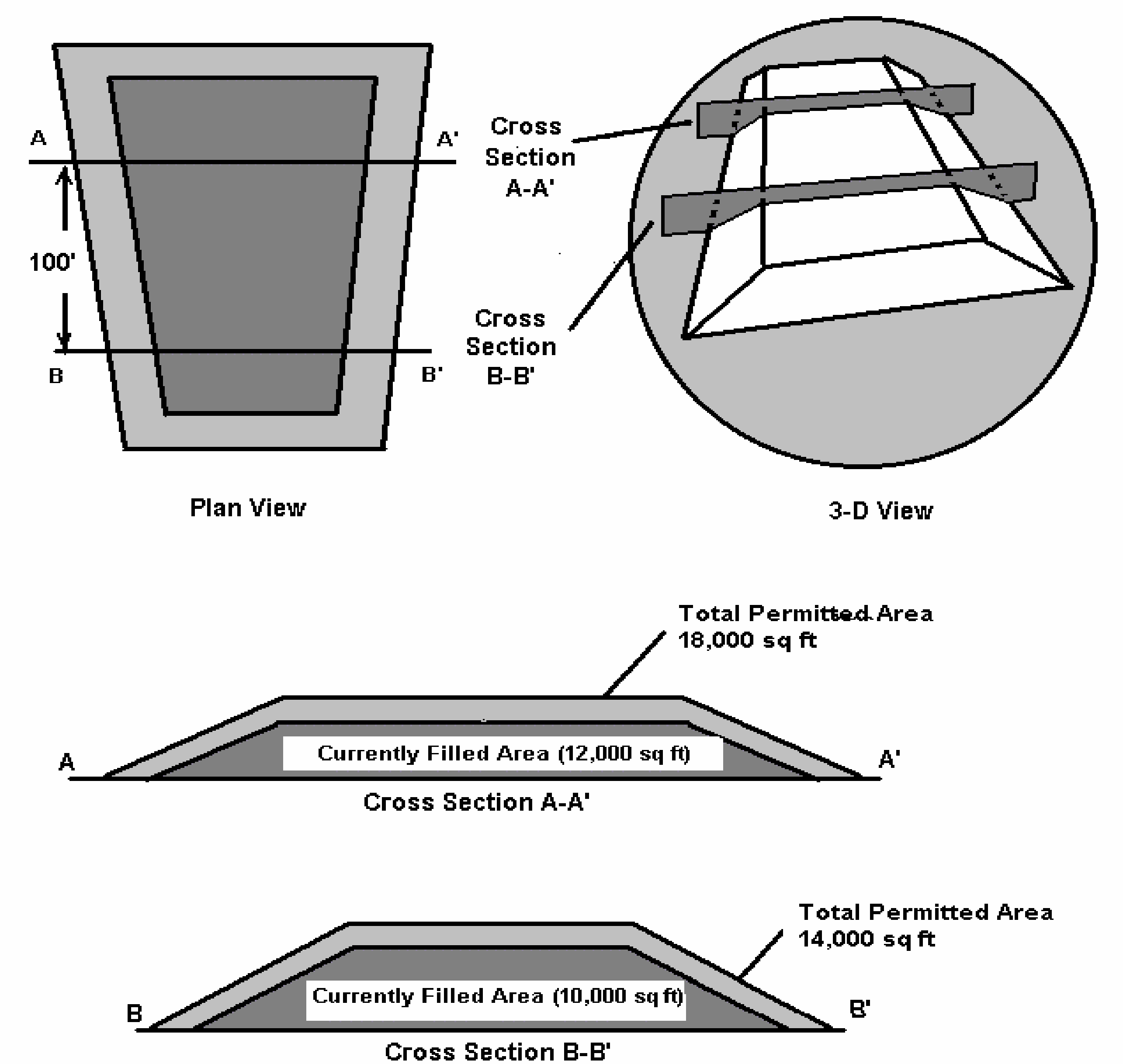
ATTACHMENT B-1

The example calculations below demonstrate how remaining capacity may be determined from a topographical map. This form of calculation is commonly referred to as the "average end method." That is because you calculate the area of two end sections and determine the volume between them. The distance between the end sections can vary depending on the size of the landfill or the need for accuracy. Generally, 100-foot cross sections are used; however, decreasing the distance to 50 feet between sections can increase the accuracy of the calculations.

In Attachment B-2, a plan view of a typical landfill is shown. The darkened area of the plan view represents the footprint of the currently filled area and the lighter area represent the footprint of the total permitted area that is yet to be filled. An additional view of the landfill is displayed in the 3-D view located to the right of the plan view. Note that corresponding cross sections for the landfill are shown for both the plan and 3-D views. The distance between the two cross sections is indicated as 100 feet. This dimension was chosen as an example only and can be shortened or enlarged as needed or as calculations necessitate. As the size of a landfill varies, so will the number of cross sections necessary to determine the remaining capacity.

Cross sections A-A' and B-B' are displayed on the lower part of the page. The darkened area of the cross sections reflect the currently filled area and the lighter shaded areas indicate the area remaining to be filled. Note that on cross section A-A' the total permitted area of 18,000 sq ft includes the 12,000 sq ft of currently filled area; therefore, only 6,000 sq ft is available for filling. Likewise the total permitted area of cross section B-B' includes the filled area of B-B'.

ATTACHMENT B-2



ATTACHMENT B-3

1. Calculate Volume for Refuse In Place:

1a. $\frac{\text{(Currently Filled Area A-A' + Currently Filled Area B-B'}}{2}$) X Distance Between A-A' & B-B' ÷ 27 CF/ 1 CY

1b. $\frac{(12{,}000 \text{ sq ft} + 10{,}000 \text{ sq ft})}{2}$ X 100 ft ÷ 27 CF/CY = **40,740 CY**

2 **Calculate Volume for Total Permitted Area:**

2a. $\frac{\text{(Total Permitted Area A-A' + Total Permitted Area B-B'}}{2}$) X Distance Between A-A' & B-B' ÷ 27 CF/ 1 CY

2b. $\frac{(18{,}000 \text{ sq ft} + 14{,}000 \text{ sq ft})}{2}$ X 100 ft ÷ 27 CF/CY = **59,260 CY**

3. Calculate Remaining Capacity in Cubic Yards

3a. Total Permitted Volume - Currently Filled Volume = Remaining Volume (Capacity)

3b. 59,260 CY - 40,740 CY = **18,520 CY**