PREDICTING LANDFILL FILLING RATES, ULTIMATE CAPACITY, AND CLOSURE DATES

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ABSTRACT

The rate at which landfill airspace is consumed, the ultimate capacity, and the expected closure date for the landfill is important to landfill owners and operators. This information is necessary to efficiently plan, operate, and close individual cells and landfills. Errors in estimating the ultimate capacity and closure date can lead to regulatory costs, interruptions of site operation, excessive gate fees, and pre-mature expenditures for landfill improvements, such as new cell construction and other alternative facilities such as transfer/materials recovery facilities. This paper presents an alternative approach for estimating the rate at which remaining airspace is consumed, and the ultimate capacity of the landfill. The approach can be applied to individual cells, or to the entire landfill. The method is applicable to both conventional and bioreactor landfills. For the method to be used, the landfill must have records on the weight of the wastes disposed to the landfill.

Most landfill operators determine the volume of waste in place and estimate the remaining capacity on an annual or more frequent basis. The volume of waste in place and the remaining air space available in the cell or the landfill are typically determined based on aerial topographic maps and volume calculations using Auto CAD software. Weigh scale records and the volume calculations are combined to determine an in-place "effective density." An estimated "future waste density" is assumed and applied to the remaining airspace to estimate the remaining capacity and the site life. The "future waste density" value cannot be determined scientifically, but its value is important to the remaining capacity and site life determinations. Conditions that make the estimate of "future waste density" problematical, include:

- Consolidation of the waste fill from surcharge effects and from decomposition of the waste materials
- Stockpiling/surcharging using soils within the landfill
- Changing waste composition
- Changes in compaction effort or equipment
- New and relocated haul roads
- Settlement of the landfill foundation

This paper presents a simplified method of estimating remaining landfill cell or ultimate landfill capacity. The method will be referred to as the "Remaining Capacity Method". The method establishes a graphical relationship between remaining airspace (cu yds) and tons of waste in place from scale records. A "best fit" curve is plotted through the data points and is extrapolated to zero remaining capacity. The corresponding tonnage at zero remaining capacity represents the ultimate weight of waste that will fit into the unit. After considering the rate at which waste is delivered to the landfill or the cell, the expected completion or closure date can be determined.

There are advantages to using the Remaining Capacity Method. Data points used to create the graphical relationship include adjustments within the landfill for conditions (see above listing) that cannot be directly measured. More importantly, the need to assume a "future waste density" is eliminated. The remaining capacity curve can be checked with each new set of data points derived from periodic aerial photographs and from gate receipts.

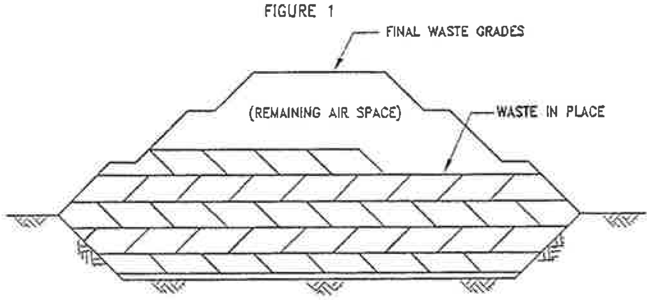
The use of the Remaining Capacity Method in estimating remaining air space capacity and predicting site life will be illustrated for an old landfill with extremely complex behavior and a new landfill cell with relatively straightforward behavior.

CONVENTIONAL AIRSPACE AND SITE LIFE ESTIMATES

Engineers and landfill operators have used various methods to estimate the remaining life of landfill sites. These methods have in common some basic elements - a determination of remaining airspace in the cell or landfill and an estimate of the density of future waste that will fill the remaining airspace. Other relevant information used in estimating site life include: tons of waste placed, the effective density of in-place wastes, refuse to soil ratios, soil stockpile source and volumes, and soil usage rates.

To calculate remaining airspace, the current landfill or cell surface is compared with the planned final grades as illustrated

FIGURE 1



on Figure 1. Topographic maps prepared from aerial photographs and site data files are used with computer software for the calculations. Airspace is expressed in terms of cubic yards (cu yds). There are adjustments to the calculated volume that may be appropriate such as the volume of soil imported for use on haul roads and soil stockpiles that may be removed from the landfill footprint. The latter would result in a larger remaining airspace since the soil will not be part of the final waste and soil matrix. Soil stockpiles used as cover remain in the landfill and neglecting any soil shrinkage or swell characteristics, result in no net gain of airspace.

The more difficult task is to estimate a realistic future density for the waste that will fill the remaining airspace. This is the point where engineers and landfill operators typically use judgement and educated guesses.

The reason that future density is hard to predict is that there may be a number of changes taking place in a landfill that can not be readily measured. They include:

Consolidation of the waste fill from surcharge effects and from decomposition of the waste materials – the organic components of typical municipal solid waste (MSW) decompose over time and are converted into gas, water, and reduced solids. The effect of the decomposition process is settlement and consolidation. A decomposed mass of waste occupies a smaller volume. The rate of decomposition varies between landfills and within a landfill. High moisture normally results in an accelerated rate of decomposition as evident in bioreactor landfills and landfills in areas of high rainfall. The resulting waste consolidation is a dynamic variable that changes over time.

Stockpiling/surcharging using soils within the landfill footprint – this process brings good news (more airspace) and bad news (difficulty in determining how much airspace has been or will be gained). Measurements of settlement and movement of soil onsite can be made, but it is not easy and leads to inaccuracy in quantifying the effects.

Changes in waste composition – as the organic fraction of the waste stream changes, so does the potential for decomposition. Changes in the waste stream impact the rate and magnitude of settlement from decomposition as evidenced by pockets of green waste in landfills that result in subsidence and sink holes. How is this impact quantified over the remaining life of a landfill?

Changes in compaction effort and equipment – the effects of a heavier or lighter compactors or additional passes on density are generally predictable, but difficult to quantify over the life of the landfill. The heavier the compactor, the higher the initial density. But how does this higher initial density impact the "future waste density" value needed for estimating ultimate landfill capacity?

New and relocated haul roads – when soil is imported into or removed from the footprint of a landfill, the volume of remaining airspace is impacted. Keeping accurate records on soil volumes is time consuming and difficult.

Settlement of the landfill foundation – this variable is not significant for most landfills, but it can be an operator's engineer's nightmare when trying to predict remaining site life at a landfill with a foundation capable of significant settlement. Predicting settlements at landfills with soft foundations is complex. The rate and magnitude of settlement changes with the surcharge (waste materials) placed.

After considering these and other factors influencing a value for future waste density, engineers and landfill operators make a judgement call or educated guess for the value. So what is the outcome likely to be? If the current "effective density" is 1,200 to 1,400 pounds per cubic yard (lb/cu yd), a value in that range may be used to predict site life. However, if the "apparent density" is 1,800, 2,000 or even 4,000 lb/cu yd (as may be experienced if large settlements have occurred between the dates of aerial photography), it is less likely that the engineer or the operator would use these values for a site life estimate. Values this high defy logic, and it is unlikely they would be acceptable to either the regulatory agencies or company management. This leaves the engineer and operator using "future waste densities" in the range of industry norms, 1,200 and 1,500 lb/cu yd.

The remaining airspace volume is then divided by the "future waste density", converted to tons, yielding the remaining site capacity in tons of solid waste. Site life is then calculated by dividing the remaining capacity by the expected future waste receipts.

The procedures described above represent a significant effort and often result in a questionable outcome. Yet these calculations are very often used to make decisions about operational planning, closure and post closure cost reserves, pricing, and future capital investments in transfer stations and equipment.

Is there a better way to determine remaining site life? We think so. Consider the following.

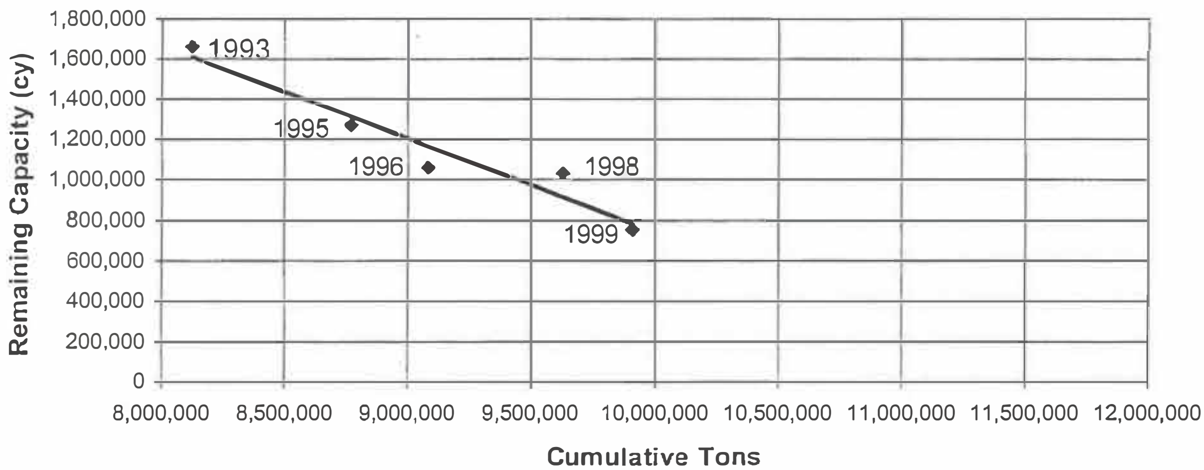
REMAINING CAPACITY METHOD

An alternative method of estimating remaining landfill or cell life is a procedure we will refer to as the "Remaining Capacity Method". This method came about as the result of a work assignment to estimate the remaining site life for a landfill that had all of the above uncertainties and probably a few that weren't so obvious. The assignment was first attempted using the Conventional Method of estimating site life. The easy part was determining the remaining airspace. Since soil stockpiles and haul roads would not be moved out of the landfill footprint, it was not necessary to adjust for that condition. Then came the estimates of waste settlement, higher density by new heavier equipment, variations in waste composition, soil surcharge effects, and foundation settlement.

After attempts to quantify the estimate of future density, it was apparent that the answer would be difficult to justify and defend. It was important to obtain an accurate site life estimate. Expected closure dates estimated previously by others had come and gone. The client was about to make a decision to purchase transfer trucks in anticipation of site closure.

We decided to focus on the information for which we had the most confidence. Remaining airspace represented such information since it was based on accurate periodic aerial photographs. To relate remaining airspace to site life, a graph was prepared relating remaining capacity to another known landfill parameter - tons of waste in-place based on scale records. The graph for this site is shown in Figure 2. The logic behind this graphical relationship is that as the wastes are placed in a landfill, they consume airspace. The graph shows the rate at which airspace is being consumed.

Figure 2



The remaining airspace in cubic yards is shown on the vertical axis, while the cumulative weight (tons) of the waste in-place is plotted on the horizontal axis. The weight of waste in place is based on historic records and annual gate receipts. Five data points representing the most reliable data were used to fit a curve using linear regression.

So what did we just do? A graphic relationship between remaining airspace and waste in-place was established that shows the rate of airspace consumption per cumulative ton of waste placed in the landfill. The landfill is telling us the rate at which remaining airspace is being consumed. We have avoided the question of "future waste density" and its many inherent uncertainties. Both remaining airspace and tons of waste in-place are reliable numbers that can be readily obtained at most landfills.

The key result from the graph is the rate at which airspace at the landfill is being consumed. This can be determined from three or more data points. Note that it isn't essential to have the cumulative total tons of waste placed in the landfill since the inception of filling, three or more sequential data points at any point in the site's history will establish the rate of airspace consumption. The rate of airspace consumption determined will also reflect the rate at which waste is being delivered to the site during the period. If the disposal rate increases or decreases significantly, a new series of three data points will be required.

This graphical solution that we have called the "Remaining Capacity Method" will now be applied to two very different landfill sites to demonstrate how it was used to estimate remaining airspace capacity and site life.

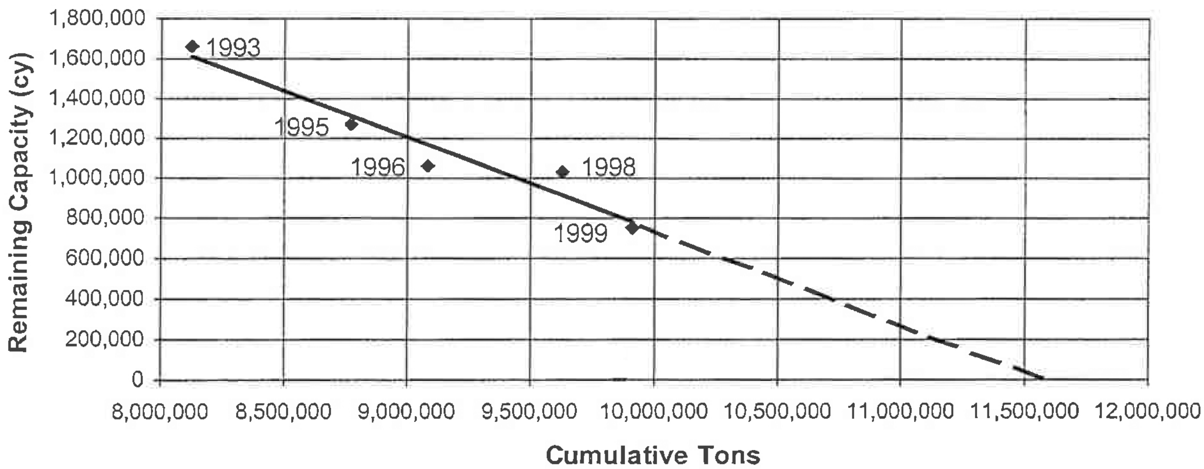
OLD COMPLEX LANDFILL

This example is the landfill that prompted the development of the Remaining Capacity Method. The landfill was an old site that had received waste from 1953 to the present. It has a footprint of approximately 160 acres and a maximum fill depth of 125 feet. The foundation is Bay Mud; a soft, compressible marine clay with inter-bedded stringers of silt, sand, and gravel. The age, height, water level, and foundation material make this site extremely complex to analyze.

The owner/operator of the site, using the Conventional Method of determining site life, estimated a remaining life of 18 months in 1994. The assumed future waste density used in that estimate was 1,110 lb/cu yd. Subsequent estimates of remaining site life in 1997, 1998, and 1999 also predicted 12 to 18 months of remaining site life at an average fill rate of 750 tpd. Yet, despite receiving the expected tonnage during the 1996 to 2000 period, the landfill still had approximately 1,000,000 cy of remaining airspace in January 2000.

SCS applied the Remaining Capacity Method to the landfill based on data points of remaining airspace and tons of waste in place from 1994 through 1999 as shown on Figure 3. A best-fit curve was plotted through the points using linear regression on an Excel spreadsheet. We then extended the line to the horizontal axis (representing zero remaining airspace) and found that the ultimate capacity was 11,600,000 tons. When the 9,912,000 tons currently in-place are subtracted from the ultimate capacity, the remaining capacity was calculated to be 1,788,000 tons. Based on a future filling rate estimate of 750 tpd, the remaining site life calculates to about 7 years. As long as the disposal rate remains at 750 tpd, the life estimate should remain valid. The landfill is currently receiving about 750 tpd and still has remaining airspace.

Figure 3



Interestingly, the slope of the graph is 1 cy of remaining airspace capacity used for 2.25 tons of waste disposed to the landfill. This represents a "future waste density" estimate for this landfill – an incredible 4,500 lb/cu yd.

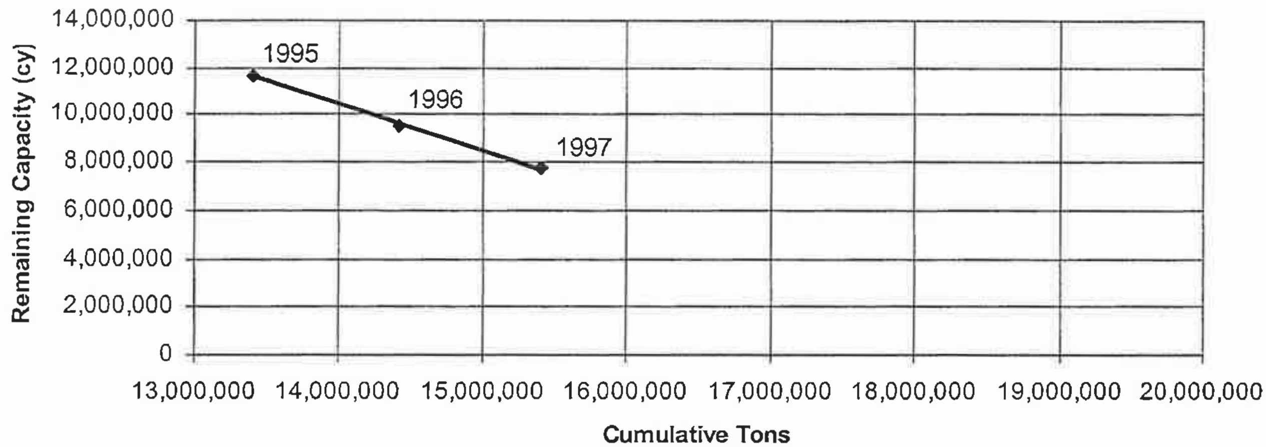
It would be hard to explain an estimated future waste density of 4,500 lb/cu yd. to a regulator or landfill owner. The high value is the result of the cumulative internal adjustments that are taking place within the entire landfill from consolidation and decomposition of wastes, foundation settlement, and other effects mentioned above. Airspace is actually being created within the landfill footprint due to these phenomena. This additional airspace is not accounted for in the remaining airspace calculation because the underlying surface of the landfill settles between the dates of the aerial photographs, resulting in an under-reporting of remaining airspace. The beauty of the Remaining Capacity Method is that it integrates all of the variables and reports the rate at which the remaining airspace is being consumed. Given a rate of waste receipts at the landfill, it allows an estimate of remaining site life without the assumptions associated with the Conventional Method calculation.

NEW LANDFILL

The County of Sacramento operates the Kiefer Landfill located near Sacramento, California. It is a Class III landfill accepting about 1,500 tpd of MSW and other mixed waste including construction debris. In years past, the waste intake has been as high as 4,500 tpd.

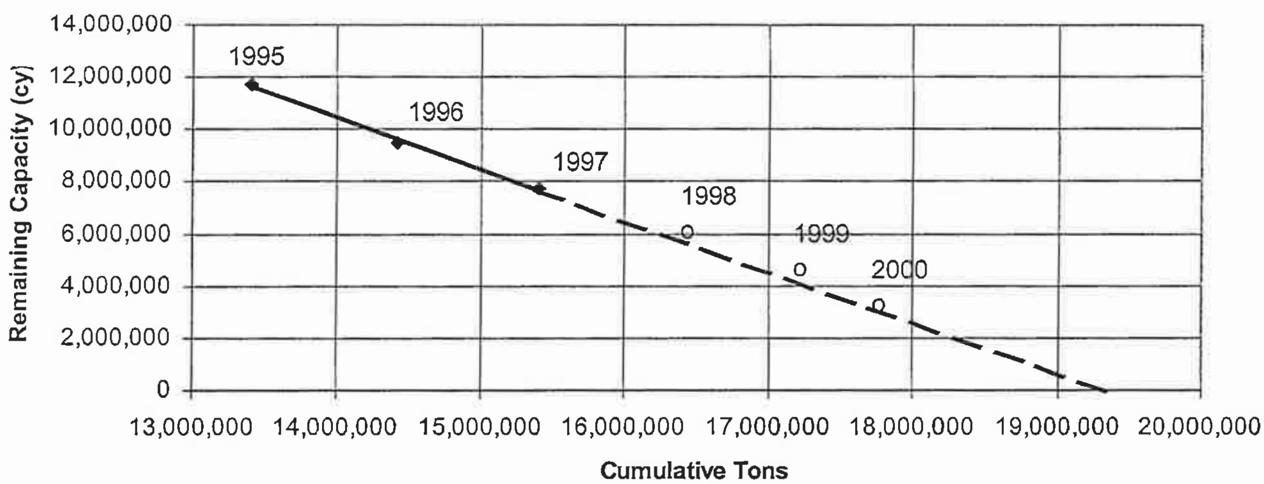
We applied the Remaining Capacity Method to data from 1995 to 1997 to see how close the method would predict airspace utilization corresponding to the actual tons of waste placed in the landfill in 1998, 1999, and 2000. All tonnage and airspace information was based on Sacramento County records. Figure 4 is a graph of the first three data sets of remaining air space and tons of waste placed. The "best fit" curve was a straight line that we extended manually to zero remaining airspace. The graph predicts that the cumulative tons of waste that can be placed in the landfill at zero remaining airspace would be 19,300,000 tons.

Figure 4



The remaining data points have been plotted on Figure 5 to see if the data fits the projected portion of the graph. As can be seen, the data points fall closely along the line, validating the relationship between remaining airspace and cumulative tons of waste placed in the landfill.

Figure 5



Based on the above examples, the Remaining Capacity Method appears to be a useful and valid alternative for predicting filling rates, ultimate capacity, and cell or landfill closure dates.

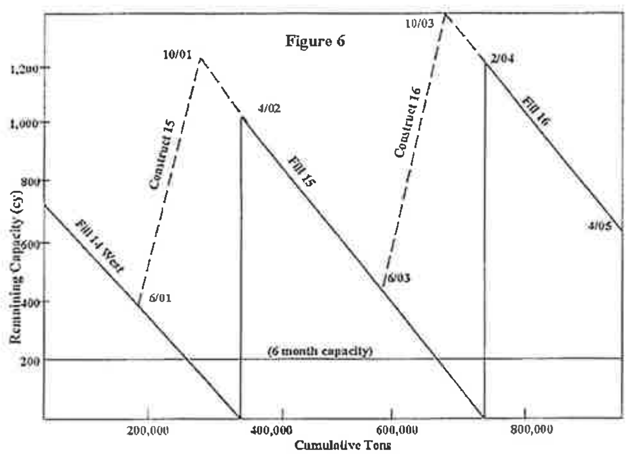
OTHER APPLICATIONS

The next example illustrates how the Remaining Capacity Method applies to a relatively new landfill cell and how it can be used to schedule cell life and construction of new cells.

Scheduling of New Cells

Scheduling cell design and construction can at times be challenging for landfill operators. Subtle changes may occur in the waste stream that affect waste density and consumption of airspace. If these changes are significant, it may be difficult to predict cell life based on conventional methods.

The Remaining Capacity Method can be used as a tool to track the behavior of the cell(s) on a periodic basis. Figure 6 is a graph of site life for three consecutive cells at a northern California landfill. Design and construction deadlines can be factored into the graph as well as a minimum reserve capacity that will always be present. Remaining airspace and cumulative tons are plotted periodically to see if they follow the graph. If a significant variation is noted, a closer look at the cell scheduling is warranted to avoid problems later in the project.



Bioreactor Landfill Performance

To monitor the anticipated performance of a bioreactor cell, a graph similar to the one for new cells would be prepared. By plotting cumulative tons and remaining airspace, the rate of filling can be tracked and the ultimate capacity predicted. If the predicted capacity falls short of the project goal, changes in the cell operation can be considered to bring the cell in at the desired capacity and life.

ACKNOWLEDGEMENTS

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