Earthwork Modeling Step-by-Step
Shrink/Swell Adjustments

Fill Factors can be entered with *Report Regions* (see page 174) and *Balance Regions* (see *Day 3 Seminar Handbook*) to adjust for cut-to-fill shrink/swell but some AGTEK users don't enter them because they prefer to make their own shrink/swell adjustments in a spreadsheet or on paper, which is perfectly fine, especially when re-compaction volumes (see *Section D* on page 219) and subsidence (see *Section E* on page 219) are involved in the earthwork analysis. Other users may want to make shrink/swell adjustments in AGTEK but hesitate doing so because they don't want to make an incorrect entry. The following discussion is intended to clarify the "why", "what" and "how" of applying shrink/swell adjustments to the AGTEK volumes (some useful references with comments are provided at the end of this discussion, on pages 223-224).

A. Three Volume/Density States of Soil

Estimating earthwork involves quantity measures in three different volume/density states: **(1)** a soil at its native undisturbed density is measured in bank cubic yards (BCY); **(2)** the same soil that has been excavated typically has a lower relative density (its volume increases) and is measured in loose ("haul" or "truck") cubic yards (LCY); and, finally, **(3)** the same soil placed as compacted fill may increase in relative density (its volume decreases) and is measured in compacted cubic yards (CCY). On projects where both cut and fill are required to establish plan subgrade, ***the difference in the relative densities of cut (BCY) and fill (CCY) must be considered to properly estimate any net volume of import or export***. Does AGTEK's volume report represent and reconcile BCY, LCY, and CCY all on one report? No, but AGTEK does allow adjustments to compensate for compaction shrink/swell between cut (BCY) and fill (CCY). *[Although the native soil's intermediate loose (LCY) volume may be used for haul production estimates (see Section F on page 222), the LCY volume is not required for a proper BCY-to-CCY compaction shrink/swell analysis of onsite excavated materials.]*

B. Estimated Shrink/Swell

Looking at the volume report on page 213, the cut (*Column F*) is interpreted as BCY and the fill (*Column G*) as CCY. The 848 CCY of total fill is multiplied by the *Comp/Ratio* of 1.15 (*Column I*—this is the *Fill Factor* that was entered with the Report Regions on pages 174, 179, 186 and 187); the product (*Column G * Column F*) of 975 (*Column K*) is the *BCY* of cut that is required to make the 848 *CCY* fill with an estimated cut-to-fill shrinkage of 15% applied. But how do we determine the appropriate AGTEK Fill Factor for a project's compaction shrink/swell adjustment?

1. Soils Report Densities

Ideally, a project soils report will provide ***existing (in-place) dry density*** and ***maximum dry density*** values for sampled onsite soils. For example, let's say a soils report indicates onsite soils with an existing dry density of **97.1 lbs/ft3**. Let's also say the soils report indicates the maximum dry density for the onsite soil is **117.5 lbs/ft3** (100% theoretical compaction—no air voids), and that the project specifications require a minimum compaction to 95% of maximum density. *[Note: The soil densities used in the following examples are stated in **lbs/ft3** (pounds per cubic foot) units; however, different sources may state densities in other units such as **lbs/cy** (pounds per cubic yard) or **kg/cm***

B. Estimated Shrink/Swell (Cont.)

(kilograms per cubic meter). Any provided unit of density can be substituted in the following shrink/swell calculations.] So, with our densities and specified compaction information in hand, we can plug the values into the formula below and calculate a corresponding shrink/swell Fill Factor for AGTEK:

*(specified compaction % / 100) * (max. density / exist. density) = AGTEK Fill Factor*

*(95 / 100) * (117.5 / 97.1) =* ***1.15*** AGTEK Fill Factor (any result **> 1** is a ***shrink*** factor)

The ***1.15*** result above is greater than 1 and, therefore, indicates that this soil will shrink from bank cut to compacted fill. This 1.15 shrink factor would be directly entered in AGTEK as a Report Region or Balance Region *Fill Factor* (page 174).

The above calculation resulted in a shrink factor, but the same formula works in cases where the provided densities and specified compaction result in cut-to-fill swell. Let's say we are provided with an existing dry density of **102.3 lbs/ft3**, a maximum dry density of **110.6 lbs/ft3** (100% theoretical compaction), and minimum compaction to 90% of maximum density. Plug these known values into the same formula to calculate the Fill Factor for AGTEK:

*(specified compaction % / 100) * (max. density / exist. density) = AGTEK Fill Factor*

*(90 / 100) * (110.6 / 102.3) =* ***0.97*** AGTEK Fill Factor (any result **< 1** is a ***swell*** factor)

The ***0.97*** result above is less than 1 and, therefore, indicates that this soil will swell from bank cut to compacted fill (at the minimum specified density). Nevertheless, this 0.97 swell factor would be directly entered in AGTEK as a Report Region *Fill Factor*. The same formula works for both shrinking and swelling soils.

Some estimators might wish to apply different AGTEK *Fill Factors* for Report Regions corresponding to different compaction requirements at structural and non-structural areas of the site. In such cases, simply plug different *specified compaction %* values into the above formula. For instance, let's say landscape areas should be compacted to no more than 85% and we are provided with an existing dry density of **97.1 lbs/ft3** and a maximum dry density of **117.5 lbs/ft3** (100% theoretical compaction). If we plug those values into the above formula, we get a *Fill Factor* of **1.03** (although, in practice, landscape areas may end up being "over-compacted" at something more than 85%).

2. Densities Not Provided

If no soils report is furnished (or the report does not include dry density data) for the site, applying a "rule of thumb" shrink/swell factor (for the site's class of soil) based on published sources is likely better than making no adjustment at all—just be aware that actual shrink/swell on any specific site can vary widely from any published shrink/swell value that you might choose to use. A number of

B. Estimated Shrink/Swell (Cont.)

2. Densities Not Provided (Cont.)

published sources are referenced on pages 223-224 but also be aware that published shrink/swell values are not standardized in terms of how they define shrink/swell and present the resulting shrink/swell values (some sources provide cut factors, some provide fill factors; some provide percentages and some provide various combinations of values). With the one exception of Atcheson (1983), the published shrink/swell sources that we reviewed do not provide shrink/swell values in a form that can be directly entered in AGTEK as a Report Region or Balance Region *Fill Factor*. With all of that said, Fill Factors can be estimated using published bank and compacted average densities for similar materials per the simple *Weight Ratio Method* discussed in the comments for Church (1981) on page 223.

Most published shrink/swell values must be converted for use in AGTEK (see the reference comments on pages 223-224 for the specific conversion formula to use for each source that we reviewed). In general, be sure any published shrink/swell values used are BCY-to-CCY and not LCY-to-CCY (using an LCY factor will overestimate the cut-to-fill shrinkage). And, if it is a BCY-to-CCY value, is it intended to adjust the cut volume or the fill volume? For example a cut-to-fill shrinkage of 15% might be listed in a table of shrink factors as "0.87" or "1.15". Both factors are mathematically equivalent and they both imply a 15% cut-to-fill shrinkage; however, 0.87 is a *cut* shrink factor and 1.15 is a *fill* shrink factor. A furnished 1.15 fill shrink factor can be entered directly in AGTEK as a Report Region or Balance Region *Fill Factor*, but a furnished 0.87 cut shrink factor must be converted to its equivalent fill shrink factor to be used as an AGTEK *Fill Factor*. The conversion is simple, (1 / 0.87) = 1.15, but the following example demonstrates the relationship between the cut shrink factor (CSF) and its equivalent fill shrink factor (FSF) ...

If this formula represents the equivalency:

$$FSF = (1 / CSF)$$

then:

$$1.15 = (1 / 0.87)$$

and:

$1.15 = 1.15$ (rounded up from 1.149)

[Note: Because the above formula can be rearranged as CSF = (1 / FSF), conversion of a fill shrink factor to its equivalent cut shrink factor is also simple: (1 / 1.15) = 0.87. This "fill factor-to- cut factor" conversion is useful should we wish to use AGTEK's ***cut shrink/swell factor*** *which is applied to cut volumes via the Edit Strata Layers dialog (discussed in detail on pages 38-39 of the Day 3 Seminar Handbook). Using cut factors in AGTEK is also the easiest way to model shrink/swell when*

B. Estimated Shrink/Swell (Cont.)

2. Densities Not Provided (Cont.)

mixed onsite cut materials are placed as fill, as discussed in the following section.]

3. Mixed Onsite Fill Materials

What AGTEK Report Region *Fill Factor* should be used when mixed onsite cut materials will be placed as fill and each material has a different shrink/swell factor?

Although this common situation is best handled using cut shrink/swell factors (as noted above), it can also be accommodated by calculating and using a volume-weighted average Fill Factor based on the BCY volume of each onsite cut material that will be placed as fill. By example, let's say that we have three different onsite cut materials (two soil types that will shrink by different amounts, plus rock that will swell) as per the following table:

Onsite Cut Material	(A) BCY Share of Fill Volume	(B) Shrink/ Swell Fill Factor	(C) Volume-Weighted Fill Factor
Soil 1	45 %	1.18	0.53
Soil 2	35 %	1.08	0.38
Rock	20 %	0.66	0.13
Total	100 %	N/A	**1.04**

The volume-weighted average Fill Factor for the materials in the above table is **1.04**, which represents an average cut-to-fill shrinkage for the combined materials of 4%. The individual volume-weighted factors in *Column C* are calculated by multiplying a material's fill volume share in *Column A* by that material's shrink/swell factor in *Column B* (for *Soil 1* the calculation is *0.45 * 1.18 = 0.53*). Once the individual volume-weighted factors are calculated, total them for the combined volume-weighted average Fill Factor. Remember, a result **> 1** is a ***shrink*** Fill Factor and a result **< 1** is a ***swell*** Fill Factor but, either way, the combined volume-weighted average is directly entered in AGTEK as a Report Region or Balance Region *Fill Factor* (page 174). See Voegele (2008) for a real-world example of the weighted-average method; see pages 41-42 of the *Day 3 Seminar Handbook* for another example of calculating and applying a volume-weighted Fill Factor, including discussion and interpretation of the resulting AGTEK strata volumes report.

C. Measured (Actual) Shrink/Swell

The above methods are used for estimating purposes *before* construction; however, ground-run GPS (or aerial drone) topo surveys make it easy to measure actual shrinkage with *before* and *after* topo data for both a cut area and the destination fill area, preferably near the start of construction (for survey data manipulations, see the *Day 2 Seminar Handbook*). Per Spahn (~1999), use the resulting topo data to calculate the cut-area and fill-area volumes then plug the volumes into the following formula to determine the actual measured shrinkage factor ...

measured cut volume (BCY) / measured fill volume (CCY) = AGTEK Fill Factor

The actual *measured* factor likely won't match the original estimated factor due to variables that may include: haul waste, over-compaction, subsidence (see *Section E* below), variations in the actual stripped topsoil depth and variations in the excavated soil's characteristics (we'll assume accurate topo data)—but that's reality and, hopefully, the actual and measured factors won't be too far apart. If this method does produce a materially different factor, make a "Save As" copy of the AGTEK job file and update the Report Regions or Balance Regions with the new measured *Fill Factor* (see pages 190-191) to see the impact on the site's total import/export; or apply the change with an exported copy of the volume report in a spreadsheet—see page 225 (*AGTEK 3D*) or 228 (*AGTEK 4D*) for export instructions. If a substantial, cost-increasing deviation between the estimated and actual factors is identified near the start of a large earthmoving operation, time may still be available to evaluate and apply potential cost-reduction strategies.

D. Shrinkage on Specified Remove/Scarify and Re-Compact Volumes

A shrinkage loss should also be estimated when removal and re-compaction (and/or scarification and re-compaction) is specified for in-place native soils. For example, let's say we have a 25,000 sq. ft. building area requiring an average re-compaction depth of 4.0 ft., of which the top 3.0 ft. must be removed and re-compacted but the bottom 1.0 ft. can be scarified and re-compacted in place. We would apply the appropriate shrinkage factor (per *Section B* above) to the entire re-compaction volume of 3,704 BCY (25,000 * 4 / 27). If the estimated cut-to-fill shrinkage is 20%, our shrinkage loss would be 741 *BCY* (3,704 * 0.20). If the entire building was a fill area, the re-compaction shrinkage increases the building's fill requirement by 741 *CCY* (to which we would then apply an appropriate fill shrink factor (e.g., 1.15): 741 * 1.15 = 852 BCY. In other words, to make the subgrade fill at the building area, we now need an additional 852 BCY of onsite cut. Many AGTEK users make shrinkage adjustments for re-compaction volumes in a spreadsheet using an exported copy of the AGTEK volume report (see pages 225 and 228 for export options).

E. Subsidence Loss Adjustment

When applicable, we may need to make a separate shrinkage adjustment in order to compensate for the immediate *shallow* subsidence of native soils due to *incidental* compaction from the earthmoving operation, even when/where re-compaction (see *Section D* above) is not specified.

E. Subsidence Loss Adjustment (Cont.)

If native soil that is cut and placed as fill is expected to shrink by some percentage, it seems logical to expect the same native soil underlying fill areas to undergo *in-place* shrinkage (by at least the same percentage) at the immediate surface of the existing ground and decreasing to 0% (no compaction effect) at some depth below the existing surface. The 0% depth will be a function of the soil type/density and the compactive effect of the earthmoving equipment running over it—it is said that large fully-loaded scrapers can have a compactive effect to a depth of 60" (48" for the heaviest rollers; and as little as 10" for farm tractors, which may be designed/selected to minimize soil compaction). Some contractors apply a subsidence adjustment to the entire disturbed area, not only to fill areas, especially in the case of tilled agricultural land. Subsidence settlements in fill areas increase the volume of compacted fill to grade, while those in cut areas decrease the volume of bank cut to grade. If a specific shallow subsidence loss is not addressed in the soils report or specifications, how can we estimate a subsidence adjustment when applicable?

Although AGTEK does not include a dedicated subsidence adjustment function, we can estimate a subsidence loss in several ways.

<u>1. Bump the Fill Factor</u>

Some users might bump the Fill Factor up by one or two percent which has the advantage of incorporating the subsidence adjustment directly into the AGTEK volumes. But this method will underestimate the adjustment on shallow fill sites and perhaps overestimate it on deep fill sites (this method is actually better suited as a means of compensating for anticipated haul waste and over-compaction loss).

<u>2. Rule of Thumb Adjustments</u>

Atherton and Alves (1986) expected settlements of at least **0.20** feet for sites on old orchards and plowed farmland, and they noted the potentially "serious effect on earthwork quantities" (consider that a 0.25 ft. subsidence settlement at an assumed affected depth of 12" represents a 25% loss by volume). Burch and Atcheson (2013) suggest a potential subsidence settlement range of **0.0** to **0.45** feet, based on existing site surface conditions. Burch and Atcheson apply the high-end of this range to sandy arid sites and to plowed fields; they apply the low-end to rocky sites and to sites with heavy pre-construction traffic (although, if any pre-construction settlement is not reflected in the bid existing topo, an estimating adjustment may still be required). Many AGTEK users apply such "rule of thumb" subsidence settlements to applicable site areas, often applying them only to fill areas—but settlement adjustments might also be applied to cut areas for one of two reasons: (1) to compensate for the relative lower density of top surface cut volumes compared to that of potentially denser underlying cut volumes, as may be experienced on some plowed sites, or (2) when reported existing densities indicate expected settlement as cut subgrade is approached. *[Remember: A subsidence settlement loss in fill areas increases the compacted fill volume required to reach subgrade, while a subsidence settlement loss in cut areas decreases the bank cut volume required to reach subgrade.]*

E. Subsidence Loss Adjustment (Cont.)

2. Rule of Thumb Adjustments (Cont.)

Regardless of the where and why, the expected settlement depth is applied to the areas shown on the AGTEK volume report (see report *Columns C* and *D* on page 213). For example, an expected 0.20 ft. subsidence applied to the total disturbed area in the *Pine Street* example would ***increase*** the fill volume by 195 BCY (0.2 * 22,879 / 27 * 1.15), ***decrease*** the cut volume by 441 BCY (0.2 * 59,600 / 27) and ***decrease*** the net export by 636 BCY (195 BCY fill + 441 BCY cut). *[Some AGTEK users take a shortcut and multiply the volume report's "**Change Per .1 Ft**" volume by the number of tenths of expected subsidence settlement (using report Column M on page 213, the shortcut calculation would be: 2 * 351 = 702 BCY), but this approach yields a larger volume because it inappropriately applies the Fill Factor adjustment to the cut area, so this shortcut method should only be used if you're happy overestimating the subsidence settlement volume (the shortcut overestimate was about 10% in this example but it will vary based on the relative areas of cut and fill).]*

3. Compaction Depth Formula

Nichols (1976) proposes the following approach for estimating subsidence ...

If we plug a 2-foot compaction depth and 15% cut-to-fill shrinkage into this formula:

*(Compaction Depth * Shrink % / 100) / 2 = Subsidence Loss (Settlement)*

Then our Subsidence Loss is calculated as: *(2 * 15 / 100) / 2 = **0.15** feet*

The calculated settlement units will match the depth units (feet, inches, centimeters, etc.); in this case, our 15% shrinkage and 2-foot compaction depth yields a subsidence settlement of ***0.15*** feet. The settlement formula averages the shrink percentage through the depth of compaction, with maximum compaction at the top and no compaction at the bottom. This approach is more rigorous because it requires us to consider the compaction depth in calculating the settlement.

4. Topo Method

If necessary, subsidence can be estimated with the topo method: (a) strip topsoil from a test area, (b) topo the stripped area, (c) proof roll the stripped area, (d) re-topo the proof-rolled area, (e) calculate the topo-to-topo volume, and (f) calculate subsidence using the formula ...

(*Topo Volume * 27) / Topo Area = Subsidence Loss [volume in cu. yds., area in sq. feet]*

Regardless of how subsidence is estimated, the estimate for this application is intended to address only immediate *shallow* subsidence due to *compaction* (compression reducing air-filled voids in the soil) and it is not intended to address longer-term subsidence due to *consolidation* (compression squeezing water out of the soil). Consolidation occurs in some soils (e.g., saturated compressible

E. Subsidence Loss Adjustment (Cont.)

clays) due to the sustained load of deep fills and/or heavy structures. Monitoring and adjusting for consolidation is typically addressed by the earthwork design and specifications.

Once the subsidence settlement value has been estimated, it can be directly incorporated into AGTEK's volume report by making a “Save As” copy of the AGTEK job file then selecting and lowering all Existing Data Lines by the indicated subsidence settlement value. If desired, the adjustment can be applied only to fill areas by making use of the Cut-Fill Lines and Trim Utilities (see the *Model Subsidence at Fill Areas* exercise in the *Day 3 Seminar Handbook*). Or apply the adjustment in a spreadsheet using an exported copy of the AGTEK volume report (see pages 225 and 228 for export instructions).

F. Haul Swell Adjustments

Swell adjustments to convert BCY to LCY for load estimates and haul costing are not intended to be entered in AGTEK for representation on the volume report, but the user can manually apply their preferred swell factors to the BCY volumes indicated on the volume report. For example, let's say the appropriate BCY-to-LCY swell factors for the *Pine Street* example are 1.30 for dirt and 1.45 for stripped topsoil. In that case, we can make LCY conversions to answer some of the questions that we might ask about the volume report’s quantities (see report on page 214) ...

1. What volume of dirt is hauled onsite (cut to fill)? 975 BCY * 1.30 = 1,268 LCY

2. What volume of dirt is hauled offsite (exported)? 2,305 BCY * 1.30 = 2,997 LCY

3. What volume of stripped topsoil should be retained onsite for re-spread purposes?
   662 BCY * 1.45 = 960 LCY

4. What volume of stripped topsoil is hauled offsite? 474 BCY * 1.45 = 687 LCY

AGTEK users can make the above swell adjustments by hand with the printed volume report (as we have here) or in a spreadsheet using an exported copy of the AGTEK volume report (see pages 225 and 228 for export instructions).

*[Note: AGTEK's Trackwork 4D product includes powerful haul planning and analysis tools—see AGTEK’s overview video at **www.agtek.com/video.html?id=580**.]*

References and *Comments*

Atcheson, Daniel. (1983). ***Estimating Earthwork Quantities***. Norseman Publishing Company. *Chapter 6 ("Soil Swell and Shrinkage") includes a table of swell and shrink factors for four generic materials (sand, gravel, clay, and dirt) in both dry and damp states at various specified densities applying both Standard and Modified Proctor tests. Atcheson's "BCY Factors" can be directly entered in AGTEK as Report Region Fill Factors.*

Atherton, Gary L. and Alves, Gerald T. (1986). ***Grading and Paving Construction: A Practical Approach to Management and Estimating***. Sandcastles Publishing. *Out of print, but it includes a brief discussion of precompaction settlement on former agricultural sites and its impact on import volumes and site balancing.*

Burch, Deryl revised by Atcheson, Daniel. (2013). ***Estimating Excavation (Revised)***. Craftsman Book Company. *See Chapter 8 ("Using Shrink and Swell Factors"). Note: Burch relied on the same generic material factors published earlier by Atcheson (1983), but Burch's "Shrink factors" express Atcheson's corresponding "BCY Factors" differently, so use this formula to convert a Burch Shrink factor to an AGTEK Report Region Fill Factor: (1 - Burch factor) + 1 = Report Region Fill Factor.*

Church, Horace K. (1981). ***Excavation Handbook***. McGraw-Hill. *Appendix 1 ("Approximate Material Characteristics") includes an extensive table of 133 excavated/mined materials providing average bank (lbs/cy in cut), loose and compacted (lbs/cy in fill) densities (swell/shrink percentages are also provided but these are not directly usable as AGTEK Report Region or Balance Region Fill Factors). AGTEK Report Region Fill Factors can be estimated with Church's material weight values using this* ***Weight Ratio Method:*** *Plug Church's listed weight values for any material into the formula where Fill Weight / Cut Weight = Report Region Fill Factor (using Church's Dry Loam weights as an example, the result is 3,520 lbs/cy / 3,030 lbs/cy = 1.16 Report Region Fill Factor). The table below presents the AGTEK Fill Factors and Cut Factors calculated for nine common materials using Church's material weights (note that a Cut Factor is simply the inverse of the corresponding Fill Factor, as discussed on page 217 of this Day 1 Seminar Handbook).*

Weight Ratio Method for Estimating AGTEK Fill/Cut Factors

	Average Weight (Lbs/CY)		BCY to CCY Shrink/Swell	
Material	**Cut (BCY)**	**Fill (CCY)**	**Fill Factor**[1]	**Cut Factor**[2]
Topsoil	2,430	3,280	1.35	0.74
Silt	3,240	3,890	1.20	0.83
Loam, Dry	3,030	3,520	1.16	0.86
Sand, Dry	2,880	3,240	1.13	0.89
Clay, Dry	3,220	3,570	1.11	0.90
Shale	4,450	2,990	0.67	1.49
Granite	4,540	3,170	0.70	1.43
Limestone	4,380	3,220	0.74	1.36
Sandstone	4,070	3,030	0.74	1.34

[1] *Fill Factor is entered in AGTEK's Report Regions dialog*

[2] *Cut Factor is entered in AGTEK's Edit Strata Layers dialog*

Tip: For readers without access to a copy of Church's "Excavation Handbook", his material shrink/swell tables (in both metric and US Customary units) are also published in Chapter 6, Section 4.6.2 of the USDOT FHWA's "Federal Lands Highway Project Development and Design Manual", which can be accessed/downloaded in PDF format at no cost via https://flh.fhwa.dot.gov/resources/design/pddm/Geotechnical_TGM.pdf#4.6.2.

References and *Comments* (Cont.)

Crooks, Alexandria. (2013). ***Application of Shrinkage and Swelling Factors on State Highway Construction*** [Master's thesis, Auburn University]. *PDF copy available online at https://etd.auburn.edu/xmlui/bitstream/handle/10415/3532/Crooks,%20Alexandria_MS%20Thesis_Spring%202013.pdf; includes a review of published shrink/swell factors, factor conversions/application calculations and a comparison of several southeastern U.S. state DOT methods of adjusting earthwork volumes for shrink/swell.*

Nichols, Herbert L., Jr. (1976). ***Moving the Earth: The Workbook of Excavation***. 3rd Ed. North Castle Books. *See "Swell and Shrinkage" discussion in Chapter 2, which is the source of the Compaction Depth formula for estimating subsidence settlement depths on page 221 of this Day 1 Seminar Handbook.*

Shanklin, Donald W., et al, eds. (2000). ***Constructing and Controlling Compaction of Earth Fills***. American Society for Testing and Materials (ASTM). *Contributed academic papers address a range of earth fill topics including compaction testing, long-term settlement in fills and their foundations, and methods of accelerating settlement.*

Spahn, Louis (~1999). ***Processing Progress Topos*** (in *AGTEK Graphic Grade GPS Hands-On Training*). Unpublished training handout, AGTEK Development Company. *No longer available, but this AGTEK training handout included a section on measuring actual cut-to-fill shrink/swell using before and after GPS topo data sets.*

Spahn, Louis (Sept./Oct. 2013). Personal telephone conversations and email correspondence. *See www.earthworksoftwareservices.com/downloads/Spahn.pdf for a biographical sketch of Louis Spahn in Harry O. Ward's "Veteran Lessons in Machine Control" article.*

Voegele, Doug (Geotechnical Section Manager, HDR Engineering). Technical Memo to Tom Barnitz, ODOT D9. (1 May 2008). ***Portsmouth Bypass Phase 1 Earthwork Factors***. *PDF copy available online at ftp://ftp.dot.state.oh.us/pub/Innovative Delivery/Portsmouth/Final_RFP/Current_All_Ref_Info/GE-Geotechnical/GE-65 Phase 1 and 3 - Technical Memo - Earthwork Factors.pdf; the document includes an example of calculating a volume-weighted average shrink/swell factor, a topic which is discussed on page 218 of this Day 1 Seminar Handbook (and pages 41-42 in the Day 3 Seminar Handbook). This Voegle document also includes a table of 60+ excavated/mined materials providing average bank (lbs/cy in cut), loose and compacted (lbs/cy in fill) densities (swell/shrink percentages are also provided but these are not directly usable as AGTEK Report Region Fill Factors). Voegele's materials appear to be a subset of those documented by Church (1981) and AGTEK Report Region Fill Factors can be estimated with the provided material weights using the Weight Ratio Method detailed in the comments for the Church reference (see previous page).*

Washington, Eugene, PE. (not dated). ***Understanding the Geothechnical Report as an Engineering and Construction Reference***. *Available online at https://pdhonline.com/courses/g106/g106.htm#!; the document provides a good introduction to the understanding and application of the geotechnical report's content, including use of compaction densities to estimate cut-to-fill shrink/swell.*

White, David J., et al. (2010). ***Earthwork Volumetric Calculations and Characterization of Additional CFED Soils - CFED Phase IV***. Earthworks Engineering Research Center (Iowa State University, Department of Civil Construction and Environmental Engineering). *PDF copy available online at www.scribd.com/document/352797986/White-Et-Al-2010-CAT-CFED-Phase-IV; among other things, the authors conducted an extensive literature review of published shrink/swell factors (including those from Burch), made adjustments for calculation differences between sources to make them directly comparable, and summarized the results in various tables. Note: Use this formula to convert these reported "Shrinkage Factors" to an AGTEK Report Region Fill Factor: (1 - Shrinkage Factor) + 1 = Report Region Fill Factor.*