BENCHMARKING HYDRAULIC DREDGE PRODUCTION

HOW DO I KNOW MY DREDGE IS PERFORMING?

Written for the aggregate producer, this report navigates the complexities of benchmarking hydraulic dredge production to assist aggregate industry professionals in determining the performance of their hydraulic dredge.

BENCHMARKING HYDRAULIC DREDGE PRODUCTION

HOW DO I KNOW MY DREDGE IS PERFORMING?

INTRODUCTION

During your career in the aggregate industry you've likely encountered professionals that have offered their opinion, with absolute certainty, as to how much your dredge should produce, even though they've examined very little, if any, of your dredging operation.

The fact is, excavating material from the earth and transporting material through a pipeline is not an opinion, but a science, and sizing up your dredge's level of performance in this process will take data and the application of some engineering.

THE BASICS

In order to best understand dredge performance, let's briefly examine how a hydraulic dredge works.

A hydraulic dredge is made up of two completely separate and independent systems working together in harmony; a material excavation system, and a material transport system. Most professionals that offer dredge productivity estimates to aggregate producers tend to only look at the transport system and ignore the excavation system altogether. This leads to confusion and frustration and can cause the aggregate producer to purchase a dredge with an undersized excavation system.

The Excavation System

With respect to a typical basket style dredge cutter head, some of the facets of the design that affect its production rate are:

- Horse Power
- Cutter Diameter
- Number of Cutter Blades
- RPM

Of the parameters shown above RPM affects the overall performance of the excavator due to its direct relationship to the breakout force produced by the excavator. Lowering the RPM increases the break out force of the cutter, while raising the RPM decreases the break out force. For this reason, dredge designers strike a balance between these two values by selecting an RPM that is just fast enough to result in a production rate that matches, or slightly exceeds the transport capability of the dredge pump, while at the same time, leaving a sufficient amount of breakout force for the material.

From the above values, an excavation rate and a material break out force are calculated, and therefore, are easily analyzed.

The three most common problems with respect to the excavation system are;

- insufficient excavator force to break out compacted materials
- improper aftermarket modifications made to screen material
- improper excavator style selection

Analyzing the excavation capabilities of the dredge is the first step in determining your dredge's production ability. For example, to illustrate how material compaction may affect your production rate, below is a comparison of production rates between a "Firm" material compaction (12 blow counts) and a "Very Hard" material compaction (50 blow counts), for four basic dredge sizes.

Firm (12) VS. Very Hard (50) Compaction

Discharge Diameter	Impeller Diameter	Prime Mover HP	HDPE Pipe	Excavator HP	Firm	Very Hard
					Average Production	Average Production
12"	32"	540	12" SDR 17	60	327	89
14"	36"	700	14" SDR 17	90	451	131
16"	40"	950	16" SDR 17	130	548	224
18"	44"	1,125	18" SDR 17	200	639	341

TABLE 1

As you can see, the results can be dramatic. An important first step in analyzing your dredge's performance is determining the compaction of your deposit, and from there, determine the excavator HP that is required. Since, the compaction of most materials fall within the "Firm" range, this is typically the compaction level on which dredge designers base their cutter designs. However, if there is heavily compacted material on your mine site, a standard dredge design may prove to be insufficient in its ability to excavate your material.

Blow count information for a deposit are often included in a Standard Penetration Test (SPT) or boring log. These tests are often performed as part of the initial survey for a potential aggregate mine site. Sometimes this data is contained in preliminary property exploratory records and may require some digging to find them, but since establishing this compaction value is an important part of your dredge performance analysis, it's worth it.

Just remember, if you can't cut it, you can't transport it.

The Transport System

The dynamics of a dredge's transport system (dredge pump) is complex and has a myriad of conditions that can greatly affect the productivity of the dredge. In order to illustrate the effects caused by these conditions, we first need to establish a benchmark, under a particular set of conditions, for some various dredge sizes. The calculated production values below, expressed in short tons per hour, and were calculated by analyzing “the transport system only” using the following common parameters:

- Well Graded Very Coarse Sand
- 30’ Terminal Discharge Elevation
- 1,000’ of Discharge Pipeline
- 30’ Dredging Depth
- Hull-Mounted Dredge Pump
- 75% Dredge Efficiency (spuds)

Discharge Diameter	Flow Rate at Peak Production	Flow Rate at Average Production	Impeller Diameter	Prime Mover HP	Pipe Size	Peak Production	Average Production
12"	4,469	5,211	32"	540	12" SDR 17	436	327
14"	6,041	7,096	36"	700	14" SDR 17	601	451
16"	8,248	9,400	40"	950	16" SDR 17	730	548
18"	11,125	12,906	44"	1,125	18" SDR 17	852	639

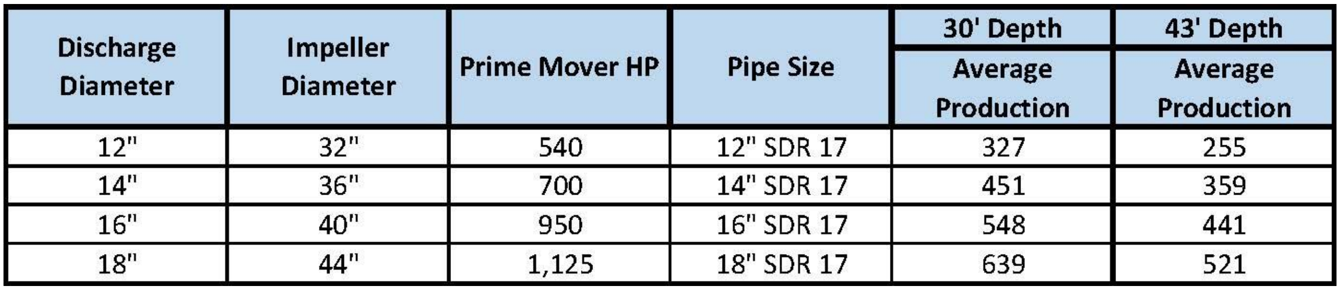
TABLE 2

Now that we’ve established reasonable production rates of the transport system, below is a list of variable parameters that can affect the production rate of a dredge’s transport system.

- Dredging Depth
- Terminal Discharge Elevation
- Discharge Pipe Diameter
- Material Gradation
- Discharge Pipe Length
- Overall Dredge Efficiency

For production comparison purposes, we’ll focus on the Average Production rate of each dredge size and apply some variations to the parameters listed above.

43’ VS. 30’ DREDGING DEPTH



Discharge Diameter	Impeller Diameter	Prime Mover HP	Pipe Size	30' Depth	43' Depth
				Average Production	Average Production
12"	32"	540	12" SDR 17	327	255
14"	36"	700	14" SDR 17	451	359
16"	40"	950	16" SDR 17	548	441
18"	44"	1,125	18" SDR 17	639	521

TABLE 3

Hull-mounted dredge pumps require atmospheric pressure to move slurry through the pump. Since a deeper dredging depth requires a longer suction pipe, and this added friction is deducted from the atmospheric pressure available, less atmospheric pressure is available to move slurry through the pump. This results in a lower production rate. As shown in the comparison chart above, the 4 dredge sizes experienced a reduction in the production rate ranging from of 72 to 118 short tons per hour.

60’ VS. 30’ TERMINAL DISCHARGE ELEVATION

60' VS. 30' Terminal Discharge Elevation

Discharge Diameter	Impeller Diameter	Prime Mover HP	Pipe Size	30' Elevation	60' Elevation
				Average Production	Average Production
12"	32"	540	12" SDR 17	327	313
14"	36"	700	14" SDR 17	451	419
16"	40"	950	16" SDR 17	548	501
18"	44"	1,125	18" SDR 17	639	581

TABLE 4

Lifting slurry higher into the air adds additional friction to the dredge pump’s discharge condition. While the pipeline length is exactly the same, the vertical column of slurry is higher and heavier, and thus requires a greater amount of energy in order to lift it. As you can see from this chart, discharge elevation of 30’ higher would result in a reduction of production rate ranging from 14 to 58 short tons per hour. A good rule of thumb is; 5’ of added elevation is equivalent to approximately 100’ of horizontal pipe friction. So, for every 5’ of elevation added, you’ll lose 100’ of discharge distance capability.

PROPER PIPE SIZE SELECTION VS. POOR PIPE SIZE SELECTION (ONE SIZE SMALLER)

Improper Pipe Size Selection

Discharge Diameter	Impeller Diameter	Prime Mover HP	Proper Pipe Size Selection	Improper Pipe Size Selection	Proper	Poor
					Average Production	Average Production
12"	32"	540	12" SDR 17	10" SDR 17	327	178
14"	36"	700	14" SDR 17	12" SDR 17	451	431
16"	40"	950	16" SDR 17	14" SDR 17	548	367
18"	44"	1,125	18" SDR 17	16" SDR 17	639	523

TABLE 5

One of the most common problems we see in our industry is utilizing an improperly sized discharge pipeline. This causes the aggregate industry to lose millions in gross revenues annually. As you can see from the chart above, an improperly sized pipe would result in a reduction of production rate ranging from 20 to 181 short tons.

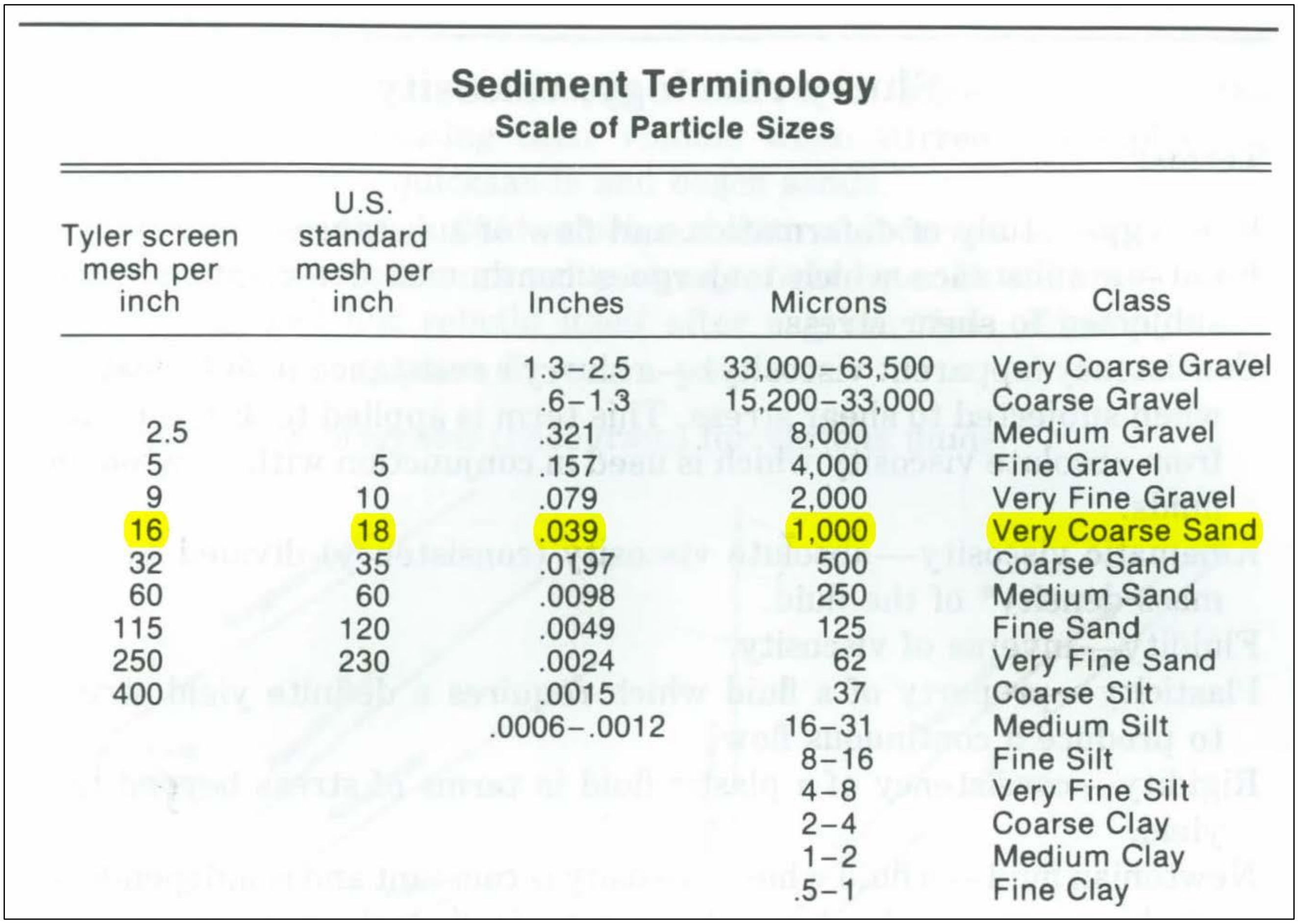
Also, if we analyze the performance of the 16” dredge with the 40” diameter impeller, we would find that when operating on the 14” SDR 17 HDPE discharge pipe, the transport system would have an output of 181 tons per hour less than when operating on 16” SDR 17 HDPE pipe. In addition, the dredge pump would operate at a 74.7% pump efficiency in 14” pipe compared to a 75.6% pump efficiency when on 16” pipe.

MATERIAL GRADATION

Another variable in the transportability of material through a discharge pipeline is gradation. While there are other material characteristics that affect the dredge’s production, such as specific gravity of the solid and shape factor of the sand particle, the gradation affects the production the most, so in this comparison, we’ll concentrate on this factor alone.

A material gradation has 2 indicators that are used to calculate the friction that will be experienced in a discharge pipeline. They are the D_{50} & D_{85} value. The D_{50} value indicates the size of sand particle that represents 50% of the mixture, meaning, 50% of the sand particles are larger, and 50% are smaller. The same principle applies to the D_{85} value, except 15% of the particles are larger and 85% are smaller. Determining the D_{85} value provides the slurry engineer with an indication as to the overall coarseness of the raw material mixture, and is a necessary data point to properly calculate the amount of friction caused by the material in a discharge pipe. Sadly, these values are rarely gathered or utilized by most.

While the D_{85} value indicates the amount of coarse or top size material that exists in a particular raw material, material classifications are based on the D_{50} value. For example, a material would be classified as a “Well Graded Very Coarse Sand if the D_{50} was approximately or equal to .039” (#16 screen). Even though the D_{85} may vary greatly, the classification would remain the same, and this variation would have a tremendous effect on the dredge’s production rate.



Sediment Terminology

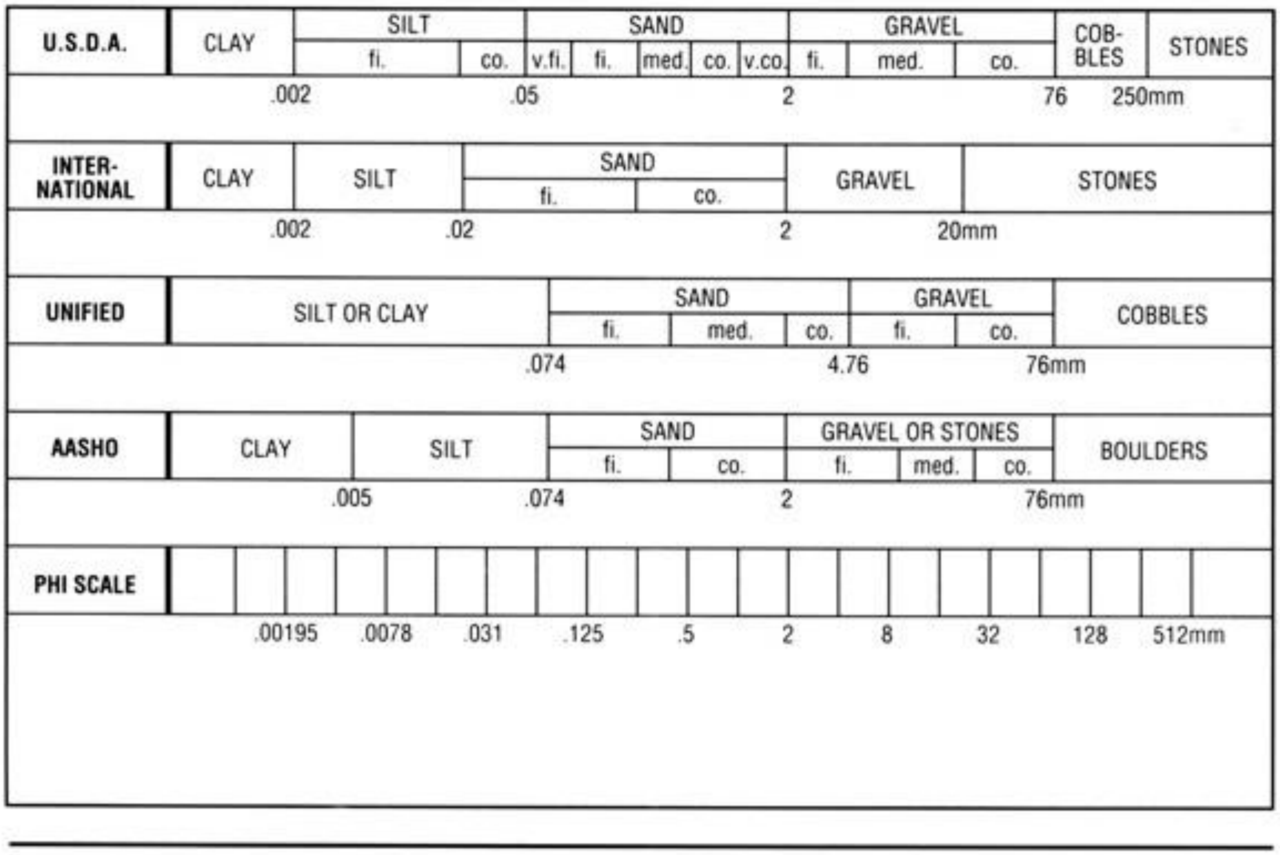
Scale of Particle Sizes

Tyler screen mesh per inch	U.S. standard mesh per inch	Inches	Microns	Class
		1.3–2.5	33,000–63,500	Very Coarse Gravel
		.6–1.3	15,200–33,000	Coarse Gravel
2.5		.321	8,000	Medium Gravel
5	5	.157	4,000	Fine Gravel
9	10	.079	2,000	Very Fine Gravel
16	18	.039	1,000	Very Coarse Sand
32	35	.0197	500	Coarse Sand
60	60	.0098	250	Medium Sand
115	120	.0049	125	Fine Sand
250	230	.0024	62	Very Fine Sand
400		.0015	37	Coarse Silt
		.0006–.0012	16–31	Medium Silt
			8–16	Fine Silt
			4–8	Very Fine Silt
			2–4	Coarse Clay
			1–2	Medium Clay
			.5–1	Fine Clay

FIGURE 1

It is important for the aggregate professional to know that many industry professionals that offer dredge production estimates use a uniform D_{50} sand particle size in their dredge production estimates, which, results in a false higher “theoretical” production rate, much higher than the expected production rate the aggregate producer will actually experience during operations. After all, when was the last time you saw a raw material where each sand particle was exactly the same uniform diameter?

In order to set a D_{85} value for a “common” sand type or soil classification, some dredge or pump professionals may turn one of 5 standards for soil classification. The 2 most common standards are the American Association of State Highway and Transportation Officials (AASHTO) and the Unified Soil Classification System (USCS). Since the classification of soils vary from one standard to the other, dredge production estimates will vary depending on which value is used by the estimator. To give you a sense of the differences, below is chart of the 5 major standards.

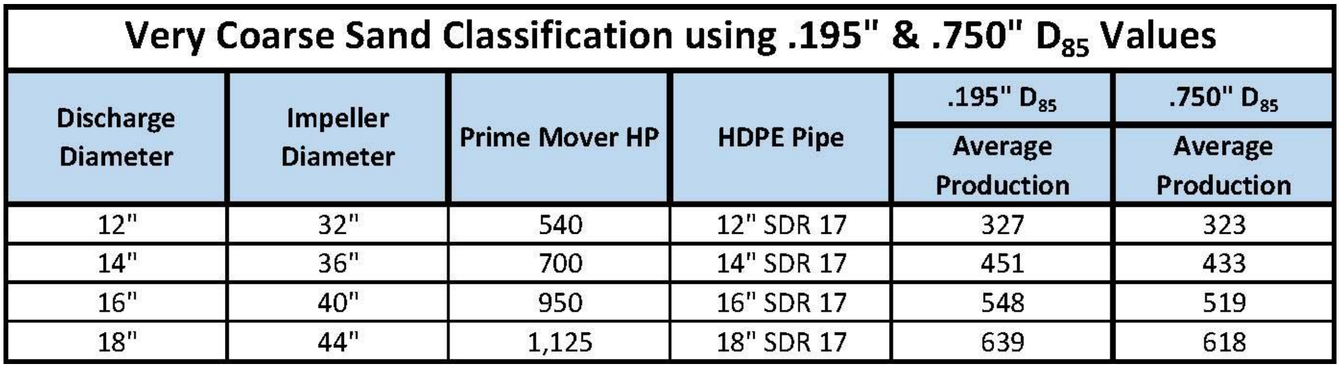


Relationships among particle size classes of 5 different systems.

FIGURE 2

A common D_{85} value used for “Very Coarse Sand” used in this paper is the AASHTO standard, which is .195”, or roughly $^{2}/_{10}$” diameter. However, what if your particular raw material on your site has a D_{85} value of, let’s say, .75” or ¾”? The actual classification of the material (based on the D_{50}) would still be classified as a “Very Coarse Sand”, but with a different D_{85} value. Would your dredge production rate be less? The answer is, yes.

Below is a production comparison of the 4 dredges used in these example, comparing “Very Coarse Sand” with D_{85} values of .195” and .750”.



Very Coarse Sand Classification using .195" & .750" D_{85} Values					
Discharge Diameter	Impeller Diameter	Prime Mover HP	HDPE Pipe	.195" D_{85}	.750" D_{85}
				Average Production	Average Production
12"	32"	540	12" SDR 17	327	323
14"	36"	700	14" SDR 17	451	433
16"	40"	950	16" SDR 17	548	519
18"	44"	1,125	18" SDR 17	639	618

TABLE 6

From the results above, even this often overlooked detail can represent a lower production estimate ranging from 4 to 29 tons per hour. While this variance represents only a slight reduction of 1.2% to 5.2%, this error coupled with other improperly assessed variables could add up to a large error in the dredge production estimate.

1,000’ VS. 2,500’ DISCHARGE DISTANCE

Quite often, and more often than you might think, we find aggregate producers pumping material on excessively long discharge pipelines in order to avoid purchasing a booster pumping station that the discharge pipeline desperately needs. In the short view, it appears that the business is saving money, when in actuality, it’s a very effective way to finance failure.

The objective of the dredge operator is to maintain a flow of slurry to the plant at a particular or reasonable velocity. As the pipeline increases in length, so does the amount of friction in the pipeline, causing the operator to increase the speed of the pump to overcome the additional friction. The process of adding pipeline and increasing speed continues until the maximum pump speed is reached. If pipeline is added after the dredge pump has reached full speed, the added friction begins to slow the slurry flow & transport rate, and production begins to decrease.

The transport production rate decreases for two reasons. Turbulence is what keeps material in suspension and is created by the slurry velocity in relation to the roughness of the pipe material. Now, let’s assume for a moment, that at a sufficient velocity, the transport pipeline has the ability to suspend a maximum density of 35% solids by weight. Because additional pipeline was added pipeline after the dredge pump full speed was reached, the flow rate has decreased, causing a reduced level of turbulence. The slurry flow rate is now only capable of suspending a maximum density of only 30% solids by weight.

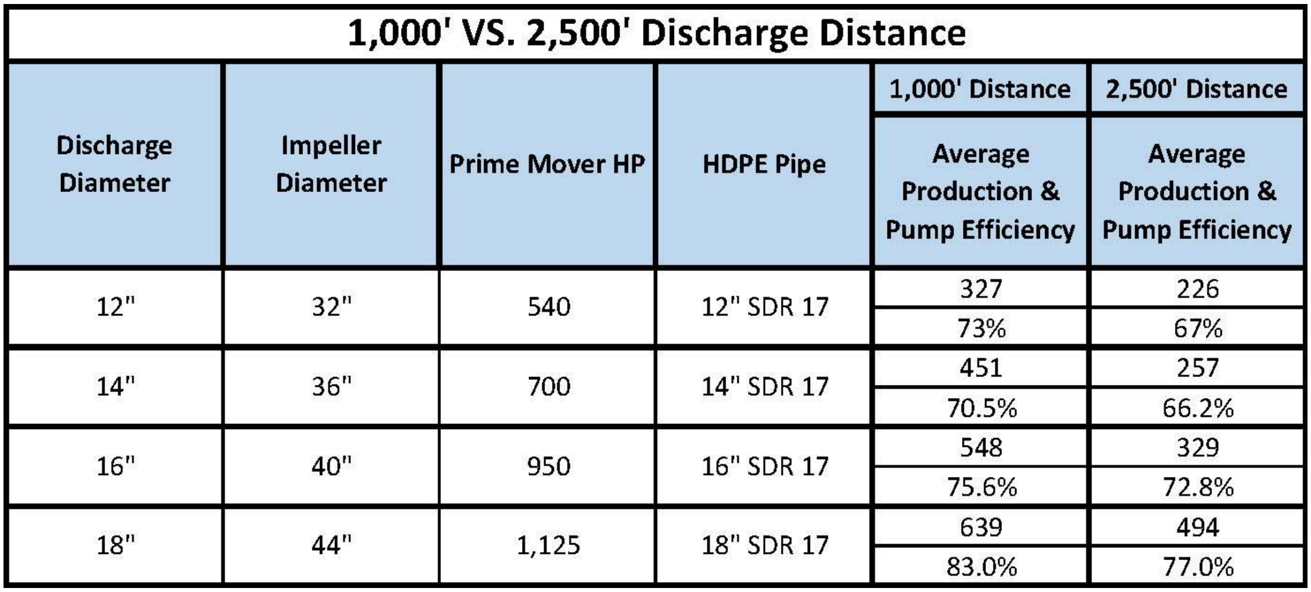
So not only has our production decreased due the lower flow rate, but the slurry is also less dense than before, adding to the decrease in production rate even further. This explains why the production rate drops so quickly as pipeline is added once full pump speed is reached.

There is yet another problem associated with this scenario, and that is, increased wear rate.

Slurry is transported in the discharge pipeline in a heterogeneous mixture, meaning, the larger sand particles are carried as a partial bed load, while lighter particles are suspended in the flow stream. As the discharge pipeline velocity is decreased, the bed load increases, causing more material to slide along the bottom of the pipeline. This increase in bed load increases the wear rate and decreases the life of the discharge pipe.

In addition, because pipeline was added after the dredge pump’s full speed was achieved, the dredge pump is operating at a lower pump efficiency. As slurry flow through the dredge pump decreased, and the pump speed remained the same, recirculation of abrasive material within the dredge pump increased. Material that once passed through the pump quickly now makes several revolutions around the pump case before leaving the volute. This reduction in dredge pump efficiency increases the pump part wear rate. As you know, dredge pump wear part are the most expensive wear parts of a dredge.

To illustrate the effect of excessively long discharge pipelines, below is a chart detailing the decrease in the production rate & dredge pump efficiency for the four dredge sizes.



1,000' VS. 2,500' Discharge Distance

Discharge Diameter	Impeller Diameter	Prime Mover HP	HDPE Pipe	1,000' Distance	2,500' Distance
				Average Production & Pump Efficiency	Average Production & Pump Efficiency
12"	32"	540	12" SDR 17	327	226
				73%	67%
14"	36"	700	14" SDR 17	451	257
				70.5%	66.2%
16"	40"	950	16" SDR 17	548	329
				75.6%	72.8%
18"	44"	1,125	18" SDR 17	639	494
				83.0%	77.0%

TABLE 7

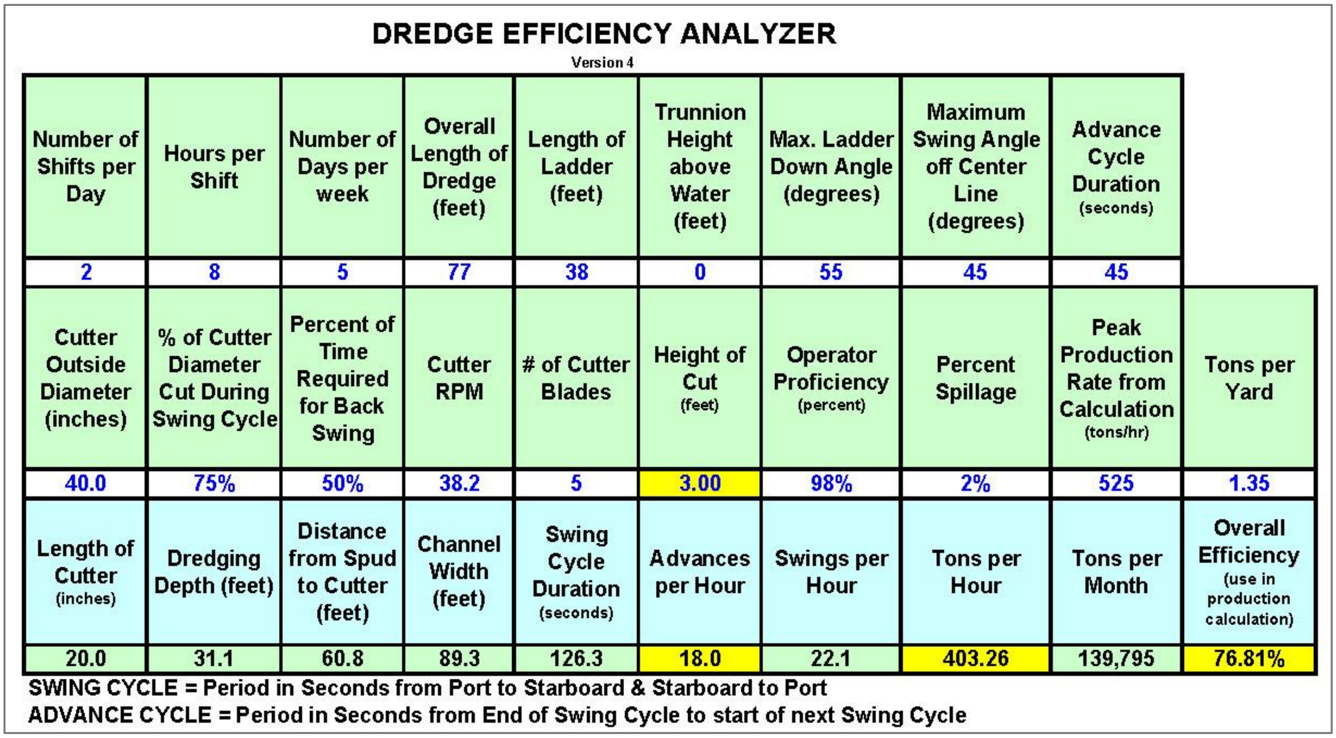
As you can see, the result is a decrease in aggregate gross revenues and a simultaneous increase in repair costs & downtime, making the addition of a booster pumping station a less expensive necessity.

OVERALL DREDGE EFFICIENCY

The production rates used in this paper are based on an overall dredge efficiency of 75%, which is an industry average for a dredge utilizing a spud style mooring system. While spud style mooring systems average 75%, a 3-wire mooring system will averages approx. 80% in overall dredging efficiency.

Overall dredging efficiency is an important factor in the proper estimation of a dredge’s production rate. Many professionals incorrectly estimate a dredge’s production rate by using the peak production rate of the transport system, and do not take into consideration any operational inefficiencies whatsoever. This estimating style is mostly used by some when representing a new dredge to a prospective buyer, but it does little to inform the aggregate professional as to the production rate they can expect in day to day operation.

While there are several measurable conditions that affect a dredge's overall efficiency, increasing the bank height can affect the production rate the most. "Bank Height", or "Height of Cut", is the height of the layer of material mined by the dredge. Mining a higher or thicker layer of material means the dredge blends a wider range of material types and spends more time dredging before a forward advance is necessary. In the example below, comparing a Bank Height of 3 feet versus 8 feet, the dredge's overall efficiency was increased in excess of 12%, and resulted in a raw material production increase of approximately 65 tons per hour, 22,749 tons monthly, or 272,988 tons annually. At an 85% utilization (85% of raw material) and an average of $8/ton selling price, this represents approximately $1,856,318 in revenue annually. As you can clearly see, overall dredge efficiency plays a significant role in the dredge production rate.



DREDGE EFFICIENCY ANALYZER

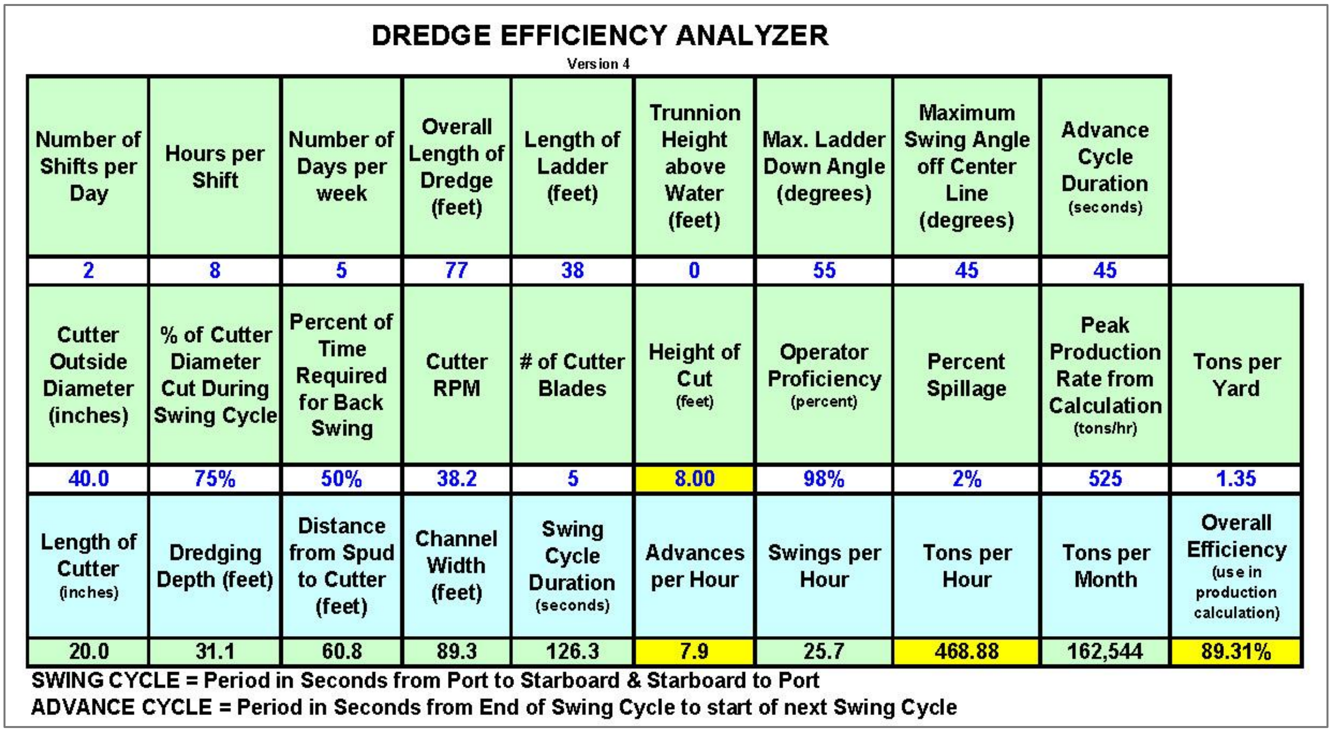
Version 4

Number of Shifts per Day	**Hours per Shift**	**Number of Days per week**	**Overall Length of Dredge (feet)**	**Length of Ladder (feet)**	**Trunnion Height above Water (feet)**	**Max. Ladder Down Angle (degrees)**	**Maximum Swing Angle off Center Line (degrees)**	**Advance Cycle Duration (seconds)**	
2	8	5	77	38	0	55	45	45	
Cutter Outside Diameter (inches)	**% of Cutter Diameter Cut During Swing Cycle**	**Percent of Time Required for Back Swing**	**Cutter RPM**	**# of Cutter Blades**	**Height of Cut (feet)**	**Operator Proficiency (percent)**	**Percent Spillage**	**Peak Production Rate from Calculation (tons/hr)**	**Tons per Yard**
40.0	75%	50%	38.2	5	3.00	98%	2%	525	1.35
Length of Cutter (inches)	**Dredging Depth (feet)**	**Distance from Spud to Cutter (feet)**	**Channel Width (feet)**	**Swing Cycle Duration (seconds)**	**Advances per Hour**	**Swings per Hour**	**Tons per Hour**	**Tons per Month**	**Overall Efficiency (use in production calculation)**
20.0	31.1	60.8	89.3	126.3	18.0	22.1	403.26	139,795	76.81%

SWING CYCLE = Period in Seconds from Port to Starboard & Starboard to Port

ADVANCE CYCLE = Period in Seconds from End of Swing Cycle to start of next Swing Cycle

TABLE 8



DREDGE EFFICIENCY ANALYZER

Version 4

Number of Shifts per Day	Hours per Shift	Number of Days per week	Overall Length of Dredge (feet)	Length of Ladder (feet)	Trunnion Height above Water (feet)	Max. Ladder Down Angle (degrees)	Maximum Swing Angle off Center Line (degrees)	Advance Cycle Duration (seconds)	
2	8	5	77	38	0	55	45	45	
Cutter Outside Diameter (inches)	% of Cutter Diameter Cut During Swing Cycle	Percent of Time Required for Back Swing	Cutter RPM	# of Cutter Blades	Height of Cut (feet)	Operator Proficiency (percent)	Percent Spillage	Peak Production Rate from Calculation (tons/hr)	Tons per Yard
40.0	75%	50%	38.2	5	8.00	98%	2%	525	1.35
Length of Cutter (inches)	Dredging Depth (feet)	Distance from Spud to Cutter (feet)	Channel Width (feet)	Swing Cycle Duration (seconds)	Advances per Hour	Swings per Hour	Tons per Hour	Tons per Month	Overall Efficiency (use in production calculation)
20.0	31.1	60.8	89.3	126.3	7.9	25.7	468.88	162,544	89.31%

SWING CYCLE = Period in Seconds from Port to Starboard & Starboard to Port

ADVANCE CYCLE = Period in Seconds from End of Swing Cycle to start of next Swing Cycle

TABLE 9

CONCLUSION

Our industry is evolving and each day becoming leaner and greener. Today, we are more aware and sophisticated, from environmental initiatives to data gathering and monitoring, and because a dredge is often the primary mining machine, a dredge analysis should play a primary role this approach.

While benchmarking a specific size dredge to a specific production rate is a desirable goal, there are far too many variables that affect its production rate to have just one benchmark. A step by step analytical approach is required to know if your dredge is truly performing to the best of its ability.

Author information:

Charlie Johnson - Director of Domestic Dredge Sales
DCS Dredge, LLC
Phone (985) 479-8042
Cell (504) 458-1810
Email chjohnson@dscdrege.com