Carbonate Rock Pore Size Distribution Determination through Iowa Pore Index Testing

Final Report
for
MLR-15-01

August 2015

Highway Division

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8. ABSTRACT

The Iowa Pore Index (IPI) measures the pore system of carbonate (limestone and dolomite) rocks using pressurized water to infiltrate the pore system. This technique provides quantitative results for the primary and capillary (secondary) pores in carbonate rocks. These results are used in conjunction with chemical and mineralogical test results to calculate a quality number, which is used as a predictor of aggregate performance in Portland cement concrete (PCC) leading to the durability classification of the aggregate.

This study had two main objectives: to determine the effect different aggregate size has on IPI test results and to establish the precision of IPI test and test apparatus. It was found that smaller aggregate size fractions could be correlated to the standard 1/2”-3/4” size sample. Generally, a particle size decrease was accompanied by a slight decrease in IPI values. The IPI testing also showed fairly good agreement of the secondary pore index number between the 1/2”-3/4”and the 3/8”-1/2” fraction. The #4-3/8” showed a greater difference of the secondary number from the 1/2”-3/4” fraction. The precision of the IPI test was established as a standard deviation (S_r) of 2.85 (Primary) and 0.87 (Secondary) with a repeatability limit (%r) of 8.5% and 14.9% for the primary and secondary values, respectively.

9. KEY WORDS

Aggregate pores, pore index test,
aggregate durability, freeze thaw durability

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INTRODUCTION

The Iowa Pore Index (IPI) test was developed in Iowa by Wendell Dubberke, a Geologist at the Iowa DOT, in the 1970's (1, 2). The test was developed as a quick screening procedure for new carbonate (limestone and dolomite) aggregate sources. The Iowa Pore Index test eventually replaced the modified ASTM C666 Freeze-Thaw test that Iowa was using at that time. This test required 90 days of cure prior to the 300 freeze-thaw cycles which took four to five months to perform. This was eventually deemed too long to wait for a test result.

The IPI test measures the amount of capillary pores (0.04 µm to 0.2 µm) in the aggregate in a matter of minutes and is much less labor intensive. The IPI test measures both larger pores and capillary pore systems by forcing water into the rock. The larger pores are determined by the volume of water forced into the pores after one minute at a pressure of 35 psi and the capillary pores are determined by the volume of water forced into the pores between one and 15 minutes at the same pressure. The test can distinguish those with extensive capillary pore systems that will likely perform poorly in freeze-thaw and those with minimal capillary pores systems that will likely perform well in freeze-thaw. For aggregates that have a marginal pore system, more extensive testing is required.

While other researchers have evaluated the IPI by trying to correlate it to the absorption test (3, 4, 5), the ASTM C666 freeze-thaw test (6, 7, 8), or to field performance (9); the IPI wasn't intended as a replacement for all other tests, evaluations, or observations. Some of the key conclusions that Wendell made from his work were:

- The pore index test is very effective in identifying aggregates with a substantial system of pores in the 0.04- to 0.2-µm diameter size.
- Nondurable, nonargillaceous carbonate aggregates associated with D-cracking pavements exhibit a predominance of 0.04- to 0.2 -µm diameter pore sizes.
- If possible, homogeneous fractions of coarse aggregates should be evaluated separately. Gravels should be separated into igneous and carbonate fractions for analysis. Individual beds of carbonate materials should be sampled separately.
- If 15 percent or more of the coarse aggregate is nondurable, the PCC will probably exhibit D-cracking.

The Iowa DOT continues to use the IPI as a component in its assessment process for the quality determination of carbonate coarse aggregates for PC concrete. There is however the potential for further refining the IPI test:

- Expand the sizes of particles that can be run in the test. The original work by Dubberke was done exclusively with material passing the 3/4" sieve and retained on the 1/2" sieve.
- Determine the repeatability of the IPI.
- Compare the IPI to modern mercury intrusion porosimetry. The original work by Dubberke was done at 35 psi with measurements taken at 1 minute and 15 minutes. Newer equipment can apply multiple pressures and make continuous measurements of the water volume changes. Modifying the IPI procedure may improve its ability to distinguish more pore size fractions.
- Examine the rock texture, grain types and pore types with thin sections and scanning electron microscopy.

OBJECTIVES

This study was designed to:

1. Expand the sizes of particles that can be run in the test.
2. Determine the single operator repeatability of the IPI.

EXPERIMENTAL APPROACH

Sample Selection

Twenty-one aggregate sources were selected based on variability in primary and secondary IPI values (observed from previous tests) as well as their chemical, or compositional (dolomite or limestone), variability. The chemical composition of each aliquot (Appendix A) was determined by X-ray fluorescence using a PANalytical AXIOSmAX. Table 1 provides information pertaining to the geologic age and formation with the corresponding source beds. Figure 1 shows the source location identified by the Table 1 Marker letter on a geologic map of Iowa. Underground mines may be in a different geologic age rock than indicated by the geologic map.

TABLE 1 Sample sources

Marker	Source Name	Beds	Formation	Age
A	Alden	0,1,3	Gilmore City	Mississippian
B	Ames Mine	47	Lime Creek	Devonian
C	Behr	1-2	Scotch Grove	Silurian
D	Bowser-Springville	6-7	Anamosa	Silurian
E	CBJ Mine	16-19	Wassonville	Mississippian
F	Dotzler	7-10A	Spillville	Devonian
G	Duenow	13	Coralville	Devonian
H	Durham Mine	101	North Hill	Mississippian
I	Dyersville-Sundheim	5-12	Hopkinton	Silurian
J	Elwood-Yeager	1-2	Scotch Grove	Silurian
K	Griffith	1-4	Gilmore City	Mississippian
L	Jones	1-4	Lithograph City	Devonian
M	Lacosta	1-4	Coralville	Devonian
N	Linwood Mine	27-30b	Otis	Devonian
O	Morgan	5	Spring Grove	Devonian
P	Portland West	1-8	Mason City	Devonian
Q	Stone City	2B-3	Scotch Grove	Silurian
R	Sully	36-41	Eagle City	Devonian
S	Warnholtz	17-18	Cedar Valley Fm	Devonian
T	Waucoma	2-5	Tete Des Morts	Silurian
U	Weeping Water Mine	9-10b	Plattsmouth	Pennsylvanian

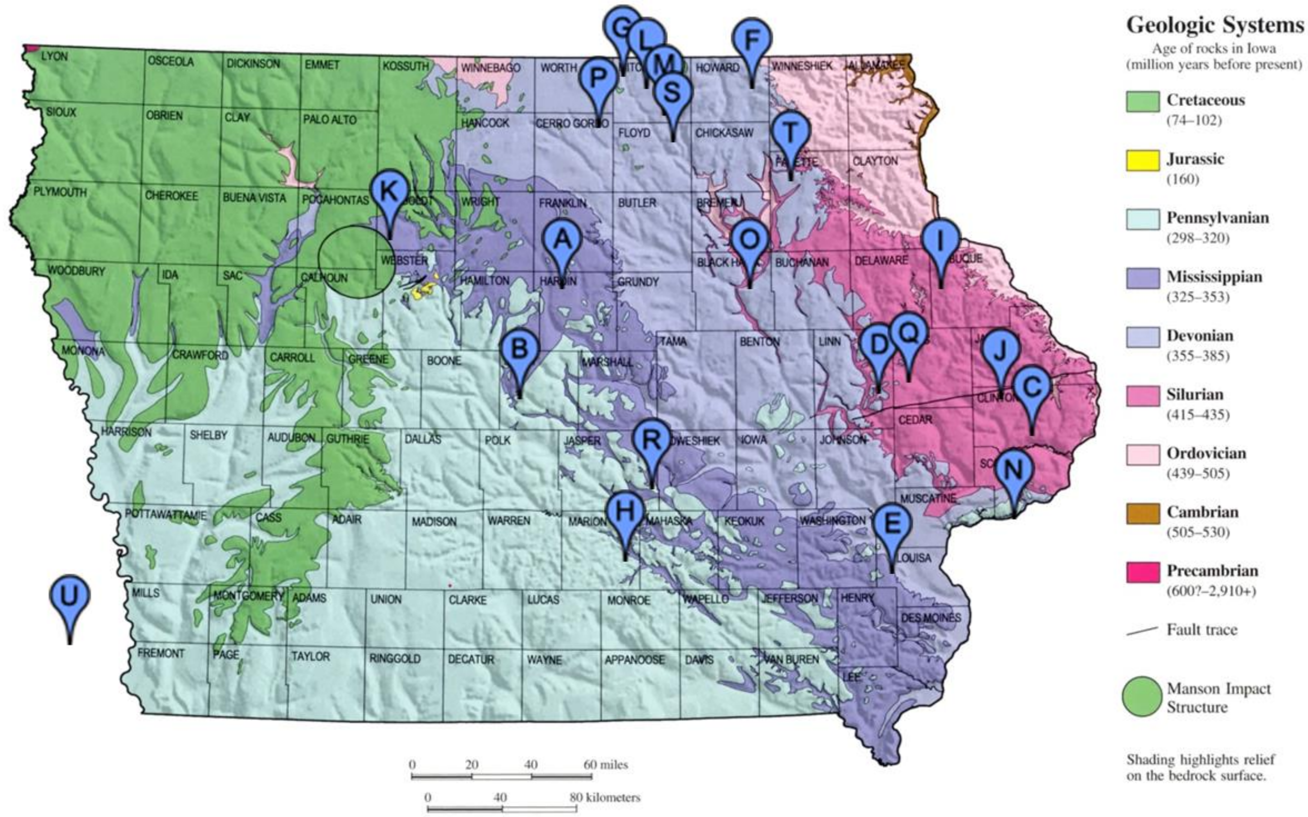

FIGURE 1 Geologic map of Iowa showing sample locations used in this study. Lettered markers correspond to "Map Marker" column in Table 1.

The Iowa Pore Index Apparatus

The Iowa Pore Index apparatus uses pressurized water as the means of measuring the pore system. The apparatus (Figure 2) contains a sample pot with hand control valve (bottom right); three graduated cylinders that measure the primary, secondary, and pot check values (shown from left to right); and the controller (left). Prior to testing a pot expansion check is run to measure the volume of water/pot expansion with no sample in the pot. This calibration involves the following procedures:

1. Secure the lid on the pot by clamping the crossbar down.
2. On the controller, turn the switch to "load," as well as on the hand control valve.
3. Turn the water on and fill the pot and graduated cylinders at a steady and controlled pace.
4. Shut the water off when the water level is on the zero mark of all three graduated cylinders by turning the hand control to run.
5. Turn the controller switch to run and hit the start button.
6. The water will pressurize to the set pot expansion value and run for a total of 30 minutes.
7. After the test is completed, turn the controller switch and hand control to drain, hit start.
8. After water is drained out, unclamp the crossbar and take off the pot lid.
9. The pot expansion is complete and ready for sample testing.

This pot expansion test must be run at least twice before testing an aggregate sample. Based on observations, the IPI apparatus regularly read a higher ml drop than it should have after the first expansion. However, the apparatus consistently read the correct pot expansion value consequent times after. Once the pot expansion is complete samples may be tested. A detailed description of the operation is in Appendix B.

FIGURE 2 Iowa Pore Index apparatus

RESULTS AND DISCUSSION

The 21 sources were first divided by size by screening over the 3/4", 1/2", 3/8", and #4 sieves. Three separate particle sizes were used in the study:

- Passing the 3/4" sieve and retained on the 1/2"sieve (standard for IPI).
- Passing the 1/2" sieve and retained on the 3/8" sieve.
- Passing the 3/8" sieve and retained on the #4 sieve.

Five 4500 gram test samples were obtained from each size fraction for each source. Two sources, Sully and Elwood-Yeager, did not have sufficient 3/8"- 1/2" material so less than five samples were obtained and tested. All samples were only run once with the exception of the Ames Mine and Alden Quarry sources. For these two sources, multiple tests were run on each 4500 gram sample. The primary (1 minute) and secondary (15 minutes) readings were recorded for every test (Appendices C and D). Table 2 displays the averages of the primary and secondary values for each 4500 gram sample with the column "Primary" being the amount of water (in ml) taken into the aggregate after one minute and the column "Secondary" after 15 minutes.

TABLE 2 Average primary and secondary IPI values by source.

	1/2"-3/4"		3/8"-1/2"		#4-3/8"	
Source	Primary	Secondary	Primary	Secondary	Primary	Secondary
Alden	76	11	75	8	69	6
Ames	13	14	13	10	14	6
Behr	133	21	123	18	111	15
Bowser-Springville	229	8	209	10	193	14
CBJ Mine	191	20	183	19	171	18
Dotzler	205	11	191	10	175	12
Duenow	16	22	16	19	19	13
Durham Mine	147	12	134	10	129	11
Dyersville-Sundheim	72	18	68	14	73	12
Elwood-Yeager	112	11	103	10	94	9
Griffith	41	22	40	14	36	8
Jones	24	22	28	22	28	16
Lacosta	16	20	16	18	17	13
Linwood	21	8	18	6	17	4
Morgan	112	10	114	10	120	12
Portland West	28	14	30	14	30	12
Stone City	245	8	231	10	205	13
Sully	172	17	163	16	147	15
Warnholtz	79	44	84	41	87	34
Waucoma	14	10	14	8	16	7
Weeping Water	16	20	19	18	21	14

Repeatability of the Iowa Pore Index Test

For the repeatability portion of the study, only the standard 1/2”-3/4” test results were used. On the Ames Mine and Alden Quarry test results, the first result was used for each of the 4500 gram samples. The analysis covered the 21 sources with 5 test results per source.

The procedure in ASTM E691 was used to determine the repeatability standard deviation and repeatability limit for the primary and secondary test results. The results are in Table 3. The variation on the primary results increased as the average values increased so a repeatability limit based on the coefficient of variation is the more appropriate limit to use. Based on the testing done, it can be stated that results of two properly conducted tests by the same operator on the same material using the same IPI are not expected to differ from each other by more than 8.5% of the average for the primary determination and 15% of the average for the secondary determination.

TABLE 3 Results of ASTM E691 analysis for the 1/2”-3/4” test results

	Primary	Secondary
Repeatability Standard Deviation (S_r)	2.85	0.87
Repeatability Limit (r)	7.9	2.4
Repeatability Limit (%r)	8.5%	14.9%

Relating Iowa Pore Index Values of Different Particle Sizes

The need to relate the standard 1/2”-3/4” to #4-3/8” arises due to chemical testing on the PANalytical AXIOSmAX. Currently, the #4-3/8” size is used in chemical tests, whereas the 1/2”-3/4” size is used in the IPI test. Since the pore systems of these two sizes are not consistent, discrepancies exist, leading to error in the quality number. To be consistent and eliminate discrepancy a correction factor was determined so the #4-3/8” size can be run in place of the standard in the IPI test. The equations below show the correction for 3/8”-1/2” and #4-3/8” to 1/2”-3/4”.

Equation 1: Secondary 1/2”-3/4” vs 3/8”-1/2”

- $y = 1.04x + 1.2$, where y is the 1/2”-3/4”and x is the 3/8”-1/2”
    - R^2=0.93
    - SEE=2.2

Equation 2: Secondary 1/2”-3/4” vs #4-3/8”

- $y = 1.09x + 2.6$, where y is the 1/2”-3/4”and x is the 3/8”-1/2”
    - R^2=0.67
    - SEE=4.8

These equations were obtained by plotting sample fractions against one another. Only the secondary IPI values are plotted since these pores are the main factor in freeze-thaw destruction. Figures 3 and 4 show the results of secondary IPI values for 1/2”-3/4” vs 3/8”-1/2” and 1/2”-3/4” vs #4-3/8”, respectively. Davis 2011 performed a similar study on Missouri aggregates and did these calculations as well, obtaining similar results. However a comparison between his data and this study is necessary to observe the different aggregate behavior. Figures 5 and 6 plot the Davis data against this study’s data with a Line of Equality for reference.

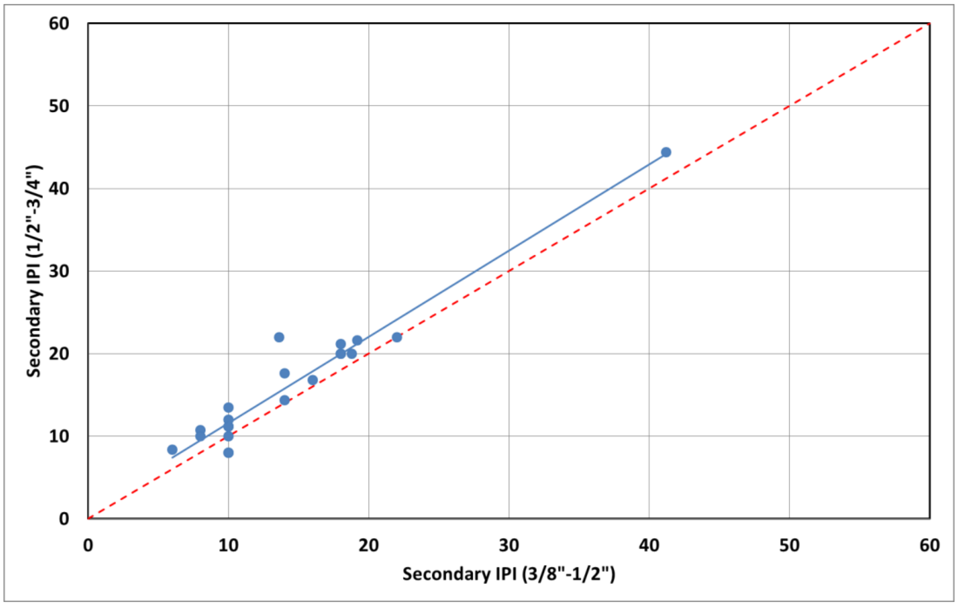

FIGURE 3 Secondary IPI values (1/2”-3/4” vs 3/8”-1/2”)

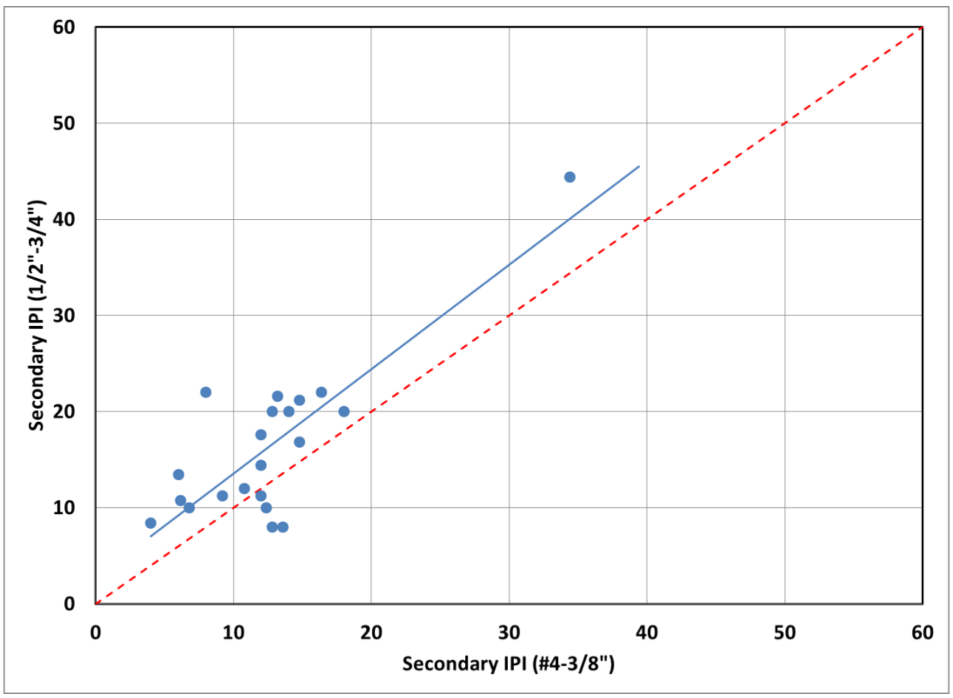

FIGURE 4 Secondary IPI values (1/2”-3/4” vs #4-3/8”)

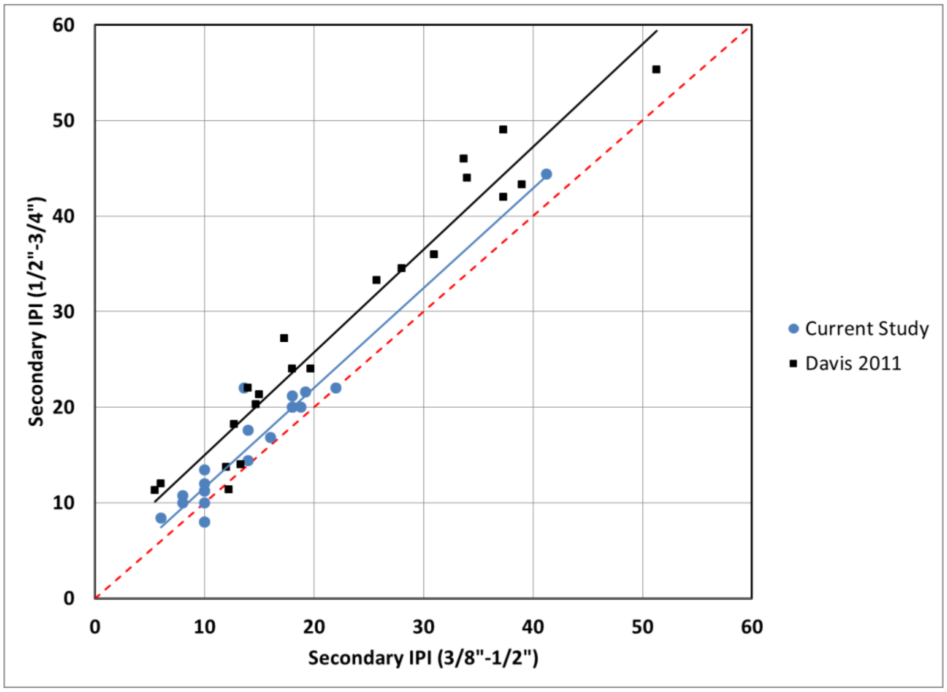

FIGURE 5 Secondary IPI values (1/2”-3/4” vs 3/8”-1/2”)

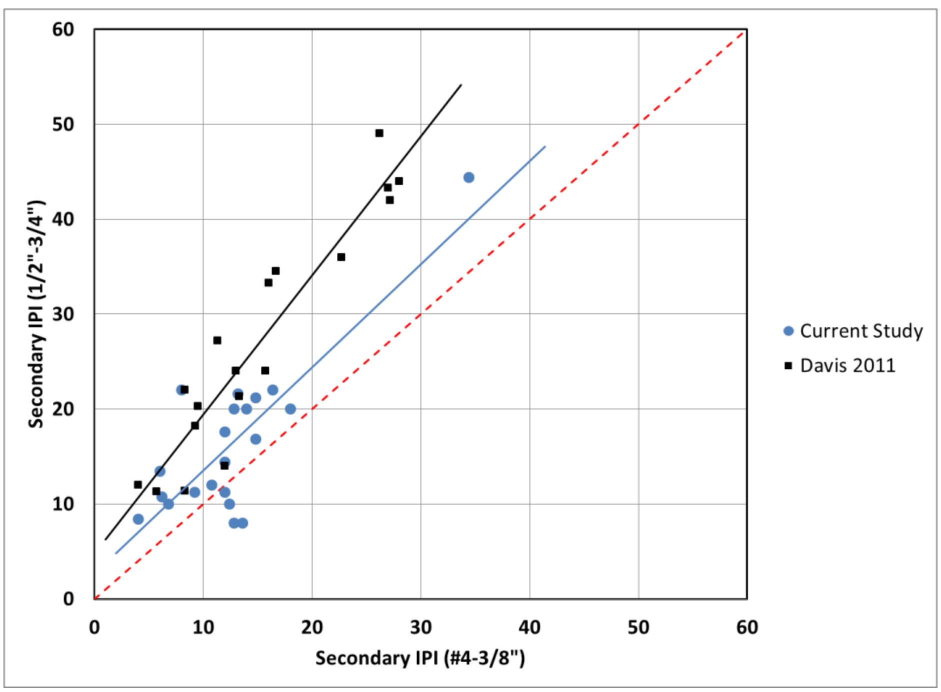

FIGURE 6 Secondary IPI values (1/2”-3/4” vs #4-3/8”)

Effect of Chemical Composition on Aggregate Quality

Studies and observations made by the Iowa Department of Transportation indicate the highest quality aggregates are classified as being a pure, or near pure, limestone ($CaCO_3$) or end member dolomite ($((Mg,Ca)CO_3)_2$). Any aggregate with a composition of 5-15% MgO are known to perform poorly. For this study, mainly high quality aggregates were tested. Figures 7 and 8 show plots each sample studied against its MgO percent. Appendix A displays each sample's bulk chemical composition. It should be noted that Warnholtz has the highest secondary IPI value (double the next highest IPI value) and is on the intermediate-end member dolomite border. Portland West has a limestone and a dolomite ledge which are quarried together.

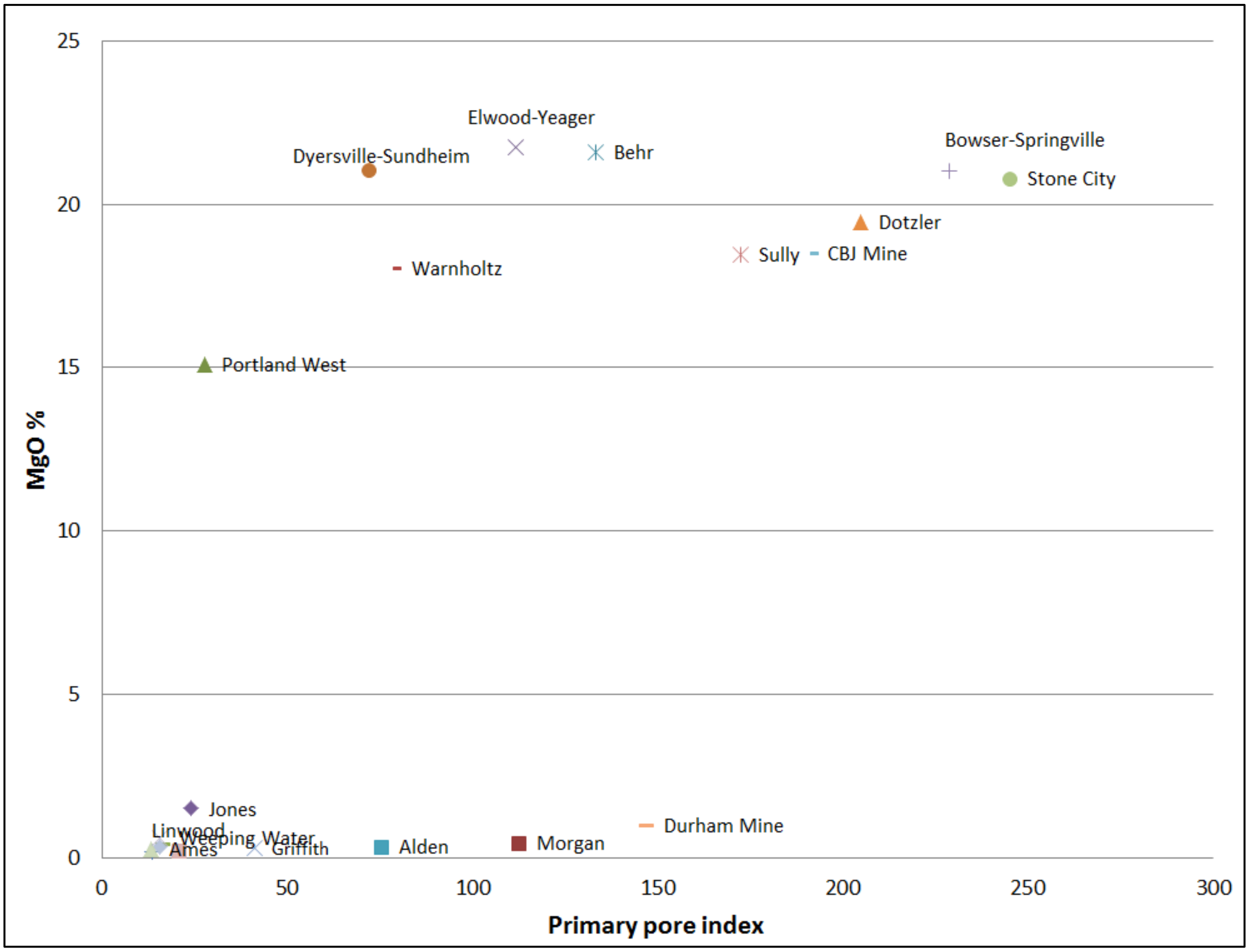

FIGURE 7 Primary IPI values of studied samples vs its MgO %.

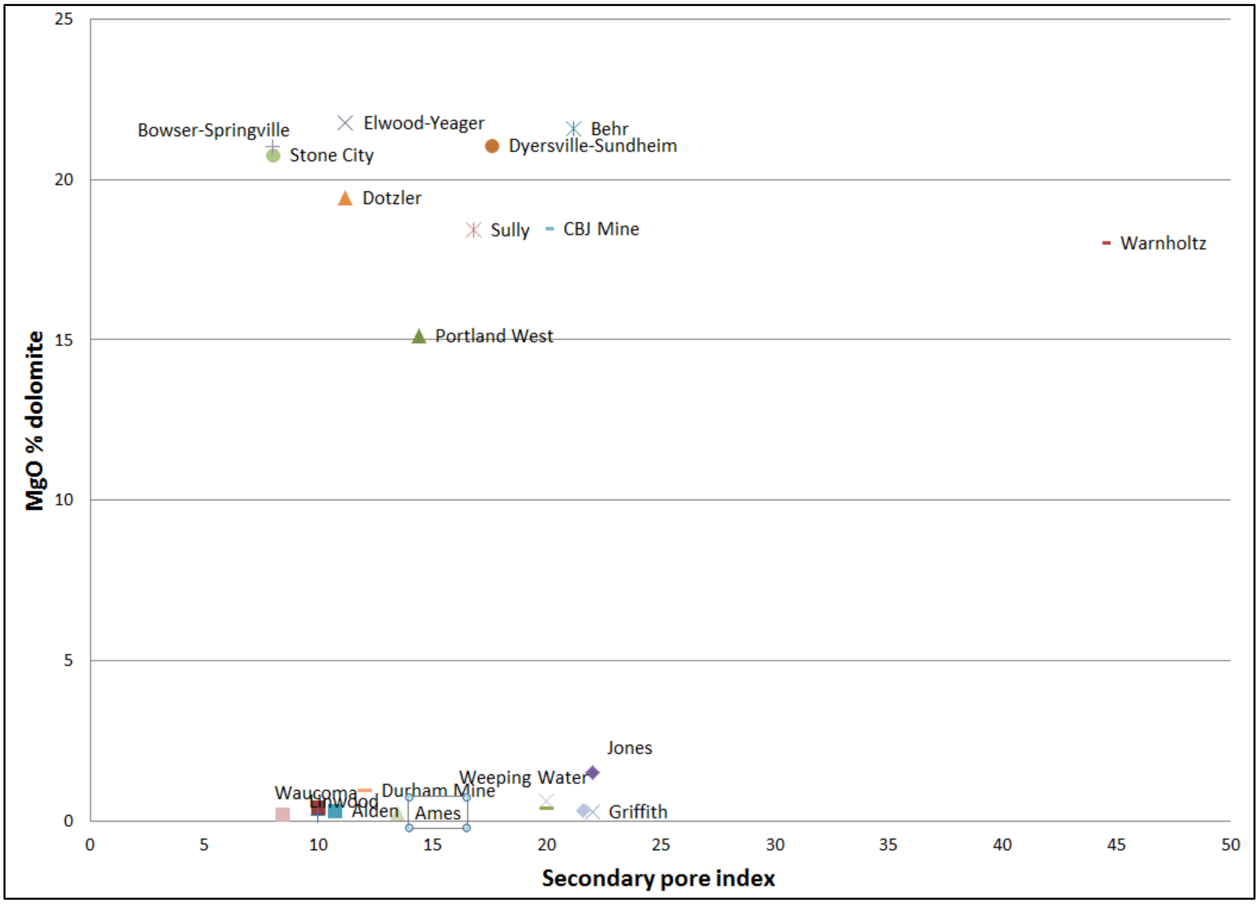

FIGURE 8 Secondary IPI values of every sample studied vs its MgO %.

Implications of Aggregate Absorptive Properties on the Iowa Pore Index

One aspect of the IPI test noted by Davis and not sufficiently addressed in the Iowa test procedure is the time it takes to fill the pot and tubes and begin the test. Davis observed bubbles in the tubes when the pot was filled too quickly. In this study it was noted that air bubbles were being released during the filling process for the more absorptive sources in the study. To quantify that initial air release in the IPI, a test was devised. The test used a 100 gram sample of aggregate in a 150 ml graduated cylinder. Water was then quickly poured into the graduated cylinder to an arbitrary level above the aggregate level and the starting volume of water noted. After one minute, the ending volume of water was recorded and subtracted from the starting volume to get the amount of water absorbed in one minute. Table 4 shows the results of that test along with the AASHTO T88 absorption values and the Primary IPI values.

The testing showed that the samples with AASHTO T88 absorption over 2.5% would absorb water prior to the start of the pressure phase of the IPI. This volume of water can significantly change the primary IPI results. The time tolerance determined and specified by Davis, 90 +/-5 seconds, is reasonable and should be included in the Iowa test procedure to improve the precision of the test.

TABLE 4 Absorption test results.

Source	Absorption T88 (%)	1 Minute Absorption ml/100 g sample	1 Minute Absorption ml/9000 g sample	Primary IPI Value
Bowser-Springville	7.49	1	90	229
Stone City	5.97	1	90	245
Morgan	5.27	2	180	112
Dotzler	4.01	1	90	205
Columbus- Junction	3.65	0.5	45	191
Sully	3.54	0.5	45	172
Durham	3.31	1	90	147
Behr	2.51	0	-	133
Elwood-Yeager	2.19	0	-	112
Warnholtz	2.16	0	-	79
Weeping Water	1.96	0	-	16
Alden	1.82	0	-	76
Dyersville-Sundheim	1.80	0	-	72
Griffith	1.68	0	-	41
Jones	0.88	0	-	24
Portland West	0.82	0	-	28
Lacosta	0.69	0	-	16
Duenow	0.66	0	-	16
Linwood	0.64	0	-	21
Ames	0.51	0	-	13
Waucoma	0.43	0	-	14

Pore System Saturation on the Iowa Pore Index

Observations throughout testing have indicated that the IPI test does not fully saturate the pore systems of aggregate. Three observations lead to this conclusion. First, when samples are tested in a clear polycarbonate vessel some aggregates released bubbles upon depressurization after testing. The pressurization forces water into the pore system, which is the fundamental mechanism the IPI utilizes to measure pore space, however air existing in the pores may compress instead of displace from the pore system. The second observation is the occurrence of a volume change in the pot check cylinder, the 15 to 30 minute period after the start of the test. The pot check cylinder volume change directly shows that water is continuing to slowly infiltrate into the pores of some aggregates. The third observation is that the weight of water forced into the aggregate is always less than what is absorbed during the T88 absorption test.

Particle Size Effects on Iowa Pore Index Values

Table 5 shows the average secondary IPI values for each sample and particle size. The IPI test generally yields secondary values that decrease or remain consistent as particle size decreases. However, some samples deviated from this trend. The four highlighted sources resulted in secondary IPI values that increased as particle size decreased. These four sources had the highest AASHTO T88 absorptions of all the samples and all were four percent or above. Further study is needed to explore the reason for this.

TABLE 5 Average secondary IPI values. Highlighted sources resulted in inverted IPI values.

Source	1/2"-3/4"	3/8"-1/2"	#4-3/8"
Alden	11	8	6
Ames	14	10	6
Behr	21	18	15
Bowser-Springville	8	10	14
CBJ Mine	20	19	18
Dotzler	11	10	12
Duenow	22	19	13
Durham Mine	12	10	11
Dyersville-Sundheim	18	14	12
Elwood-Yeager	11	10	9
Griffith	22	14	8
Jones	22	22	16
Lacosta	20	18	13
Linwood	8	6	4
Morgan	10	10	12
Portland West	14	14	12
Stone City	8	10	13
Sully	17	16	15
Warnholtz	44	41	34
Waucoma	10	8	7
Weeping Water	20	18	14

Surface Area and Mass Effects on Iowa Pore Index Values

As detailed earlier, most sources tested had a slight decrease or remained consistent in the secondary IPI values with smaller particle sizes. These results are using the same sample size (mass) of each particle size fraction. Only four of the 21 sources showed an increase of the secondary IPI with smaller particle sizes. This is significant because early working hypotheses regarding the available pore space assumed that consistent results of different particle sizes would be controlled by surface area of the sample particles and not the sample mass. As the particle size decreases, with the same sample mass, the surface area of the sample increases. Previous tests (not reported) adjusted the sample mass to retain an approximately equivalent sample surface area, based on a rectangular prism particle shape. When the sample weight was adjusted to produce equal surface areas for all particle size fractions the IPI data did not correlate. These results indicate that surface is not a controlling factor in the available secondary IPI volume.

CONCLUSION AND RECOMMENDATIONS

Aggregate quality determination is essential for Portland cement concrete performance and longevity. The Iowa Pore Index combined with chemical and mineralogical studies provide integral data used to assess quality. The deterioration of PCC is largely a function of the aggregate pore size distribution. The IPI test provides a means of measuring the amount of primary and secondary or capillary pores. These capillary pores are believed to allow extensive freeze-thaw damage to occur, therefore determination of aggregate sources with high secondary IPI values is essential for PCC pavement durability.

This study accomplished the two main objectives, the establishment of the IPI test single operator precision and the development of a correction factor relating the standard sample particle size of 1/2”-3/4” to 3/8”-1/2” and #4-3/8”. The correction factor permits the use of smaller particle sizes for the test when enough or no 1/2”-3/4” fraction particles are not available.

One aspect of the study that is still unanswered is the reason(s) for the change in the IPI secondary test results when the sample particle size is changed. Crushing the aggregate into smaller sizes may change the pore structure due to preferential cracking. To answer this, future research should include Mercury porosimetry as a test method designed to fully saturate and measure pore size distribution. This test can reach extremely high pressures. Mercury is able to infiltrate a wide range of pore sizes at a variety of different pressures, producing a finer resolution data set. Thin section analysis of samples is also essential for complete understanding of carbonate pore systems. Thin section analysis would allow for void space size determination with a much greater range of identification than the IPI can test. Future research taken to combine mercury porosimetry with thin section analysis would produce the most accurate pore size distribution data.

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Appendix A
Sample Bulk Chemical Composition

Table Appendix A.1. Bulk chemical composition of the three size fractions used from the study aggregate sources.

Source / County	Size fraction	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Cl	TiO_2	S	Na_2O	K_2O	P_2O_5	MnO	SrO
ALDEN / HARDIN	1/2-3/4	54.11	0.31	0.10	0.04	0.268	0.015	0.002	0.046	0.028	-0.003	0.023	0.021	0.033
ALDEN / HARDIN	3/8-1/2	54.18	0.31	0.10	0.04	0.184	0.015	0.004	0.041	0.026	-0.003	0.022	0.020	0.035
ALDEN / HARDIN	No.4-3/8	53.15	0.17	0.09	0.03	0.290	0.015	0.003	0.062	0.021	-0.004	0.022	0.021	0.035
AMES / STORY	1/2-3/4	54.79	0.26	0.36	0.13	0.164	0.007	0.009	0.073	0.015	0.034	0.003	0.008	0.028
AMES / STORY	3/8-1/2	54.96	0.33	0.40	0.14	0.154	0.008	0.009	0.073	0.032	0.034	0.004	0.007	0.030
AMES / STORY	No.4-3/8	53.98	0.24	0.27	0.11	0.135	0.007	0.007	0.069	0.011	0.025	0.002	0.008	0.030
BEHR / CLINTON	1/2-3/4	30.78	21.58	0.25	0.11	0.279	0.128	0.003	0.007	0.063	0.014	0.013	0.008	0.004
BEHR / CLINTON	3/8-1/2	30.91	22.04	0.21	0.09	0.275	0.121	0.002	0.008	0.065	0.010	0.013	0.011	0.004
BEHR / CLINTON	No.4-3/8	30.89	21.15	0.22	0.10	0.273	0.108	0.005	0.008	0.058	0.010	0.012	0.009	0.004
BOWSER / LINN	1/2-3/4	30.69	21.04	0.49	0.09	0.129	0.051	0.004	0.020	0.029	0.036	0.000	0.009	0.005
BOWSER / LINN	3/8-1/2	30.95	21.37	0.55	0.10	0.128	0.055	0.003	0.020	0.045	0.044	0.000	0.008	0.007
BOWSER / LINN	No.4-3/8	30.87	20.94	0.69	0.12	0.141	0.054	0.006	0.021	0.033	0.053	0.000	0.010	0.005
COLUMBUS. / LOUISA	1/2-3/4	29.13	18.48	5.31	0.77	1.586	0.051	0.031	0.085	0.063	0.201	0.044	0.107	0.002
COLUMBUS. / LOUISA	3/8-1/2	28.42	17.89	7.12	0.80	1.591	0.051	0.030	0.085	0.050	0.208	0.048	0.106	0.002
COLUMBUS. / LOUISA	No.4-3/8	28.61	18.05	7.07	0.76	1.584	0.051	0.029	0.097	0.056	0.205	0.049	0.107	0.002
DOTZLER / HOWARD	1/2-3/4	33.46	19.44	0.35	0.09	0.352	0.031	0.006	0.128	0.030	0.026	0.010	0.040	0.004
DOTZLER / HOWARD	3/8-1/2	32.42	20.34	0.44	0.11	0.437	0.032	0.007	0.170	0.033	0.038	0.011	0.041	0.003
DOTZLER / HOWARD	No.4-3/8	36.08	16.49	0.39	0.10	0.418	0.028	0.008	0.140	0.025	0.032	0.010	0.044	0.004
DUENOW / MITCHELL	1/2-3/4	54.91	0.33	1.10	0.24	0.101	0.008	0.014	0.048	0.005	0.110	0.006	0.003	0.014
DUENOW / MITCHELL	3/8-1/2	54.16	0.86	1.05	0.23	0.126	0.010	0.013	0.057	0.008	0.103	0.006	0.005	0.015
DUENOW / MITCHELL	No.4-3/8	53.41	0.96	1.70	0.34	0.173	0.011	0.017	0.060	0.009	0.159	0.007	0.005	0.014
DURHAM / MARION	1/2-3/4	53.25	0.97	1.82	0.25	0.386	0.027	0.015	0.180	0.039	0.120	0.003	0.012	0.032
DURHAM / MARION	3/8-1/2	52.94	0.96	1.92	0.26	0.401	0.027	0.017	0.189	0.083	0.127	0.003	0.012	0.029
DURHAM / MARION	No.4-3/8	51.83	0.98	1.95	0.26	0.489	0.027	0.015	0.215	0.031	0.124	0.003	0.012	0.029
DYERSVILLE / DUBUQUE	1/2-3/4	30.36	21.07	0.67	0.12	0.191	0.149	0.007	0.013	0.064	0.058	0.002	0.010	0.004
DYERSVILLE / DUBUQUE	3/8-1/2	30.76	21.45	1.17	0.23	0.217	0.158	0.012	0.018	0.076	0.109	0.003	0.012	0.004
DYERSVILLE / DUBUQUE	No.4-3/8	30.32	20.42	1.98	0.41	0.237	0.143	0.019	0.019	0.067	0.160	0.003	0.012	0.004
ELWOOD / CLINTON	1/2-3/4	30.63	21.76	0.27	0.06	0.487	0.148	0.002	0.010	0.130	0.013	0.013	0.009	0.003
ELWOOD / CLINTON	3/8-1/2	30.64	21.18	0.35	0.08	0.484	0.151	0.004	0.011	0.118	0.020	0.017	0.009	0.003
ELWOOD / CLINTON	No.4-3/8	30.29	20.44	0.27	0.07	0.579	0.136	0.004	0.010	0.120	0.013	0.011	0.009	0.003

Source / County	Size fraction	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Cl	TiO_2	S	Na_2O	K_2O	P_2O_5	MnO	SrO
GRIFFITH / HUMBOLDT	1/2-3/4	55.95	0.28	0.19	0.07	0.119	0.008	0.002	0.010	0.031	0.009	0.005	0.005	0.031
GRIFFITH / HUMBOLDT	3/8-1/2	56.11	0.54	0.20	0.07	0.137	0.009	0.003	0.013	0.028	0.009	0.006	0.006	0.031
GRIFFITH / HUMBOLDT	No.4-3/8	56.00	0.32	0.25	0.08	0.156	0.008	0.006	0.012	0.023	0.013	0.005	0.007	0.031
JONES / FLOYD	1/2-3/4	52.62	1.50	1.60	0.34	0.212	0.011	0.018	0.064	0.014	0.159	0.006	0.006	0.019
JONES / FLOYD	3/8-1/2	52.96	1.53	1.21	0.26	0.162	0.012	0.014	0.039	0.021	0.107	0.006	0.006	0.017
JONES / FLOYD	No.4-3/8	51.75	2.46	1.40	0.31	0.173	0.014	0.015	0.038	0.015	0.126	0.006	0.006	0.017
LACOSTA / FLOYD	1/2-3/4	54.70	0.39	1.11	0.24	0.144	0.009	0.012	0.037	0.017	0.099	0.006	0.005	0.018
LACOSTA / FLOYD	3/8-1/2	54.76	0.54	1.30	0.27	0.138	0.009	0.017	0.047	0.007	0.114	0.006	0.005	0.020
LACOSTA / FLOYD	No.4-3/8	53.93	0.73	1.29	0.27	0.175	0.010	0.016	0.044	0.008	0.115	0.007	0.005	0.018
LINWOOD / SCOTT	1/2-3/4	55.41	0.22	0.56	0.11	0.100	0.009	0.005	0.056	0.013	0.040	0.005	0.035	0.011
LINWOOD / SCOTT	3/8-1/2	54.05	1.06	0.73	0.18	0.246	0.012	0.009	0.088	0.017	0.068	0.005	0.040	0.011
LINWOOD / SCOTT	No.4-3/8	52.31	2.04	0.66	0.16	0.476	0.015	0.006	0.089	0.014	0.058	0.007	0.071	0.009
MORGAN / BLACK HAWK	1/2-3/4	55.84	0.43	0.15	0.01	0.140	0.012	0.002	0.056	0.042	-0.001	0.007	0.021	0.009
MORGAN / BLACK HAWK	3/8-1/2	54.88	0.94	0.27	0.03	0.230	0.013	0.003	0.058	0.055	0.006	0.008	0.024	0.008
MORGAN / BLACK HAWK	No.4-3/8	54.65	0.91	0.35	0.04	0.433	0.013	0.002	0.154	0.053	0.014	0.008	0.023	0.008
PORTLAND / CERRO GORDO	1/2-3/4	37.19	15.11	1.29	0.28	0.712	0.048	0.014	0.161	0.068	0.119	0.003	0.032	0.011
PORTLAND / CERRO GORDO	3/8-1/2	38.06	13.69	1.60	0.33	0.841	0.048	0.017	0.186	0.059	0.132	0.004	0.036	0.010
PORTLAND / CERRO GORDO	No.4-3/8	39.41	12.36	1.64	0.39	1.232	0.041	0.020	0.358	0.049	0.143	0.006	0.039	0.012
STONE CITY / JONES	1/2-3/4	30.40	20.78	2.04	0.28	0.206	0.049	0.016	0.015	0.034	0.144	0.003	0.015	0.004
STONE CITY / JONES	3/8-1/2	30.62	20.47	2.05	0.29	0.210	0.053	0.016	0.017	0.028	0.151	0.004	0.016	0.004
STONE CITY / JONES	No.4-3/8	29.85	19.77	4.30	0.33	0.224	0.048	0.018	0.016	0.014	0.169	0.003	0.016	0.003
SULLY MINE/JASPER	1/2-3/4	31.89	18.44	3.99	0.70	0.616	0.037	0.038	0.195	0.031	0.202	0.010	0.047	0.002
SULLY MINE/JASPER	3/8-1/2	33.46	17.45	2.49	0.44	0.437	0.036	0.027	0.076	0.035	0.126	0.011	0.044	0.003
SULLY MINE/JASPER	No.4-3/8	32.04	17.98	2.76	0.44	0.469	0.036	0.023	0.080	0.034	0.128	0.010	0.043	0.002
WARNHOLTZ / FLOYD	1/2-3/4	32.07	18.02	4.30	1.03	0.493	0.048	0.040	0.170	0.045	0.381	0.007	0.014	0.011
WARNHOLTZ / FLOYD	3/8-1/2	34.12	15.45	4.52	1.06	0.503	0.041	0.044	0.166	0.032	0.385	0.007	0.014	0.012
WARNHOLTZ / FLOYD	No.4-3/8	34.18	15.49	4.60	1.08	0.492	0.041	0.047	0.162	0.022	0.397	0.007	0.013	0.012
WAUCOMA / FAYETTE	1/2-3/4	55.62	0.19	0.30	0.07	0.071	0.009	0.008	0.001	0.014	0.018	0.004	0.000	0.008
WAUCOMA / FAYETTE	3/8-1/2	55.73	0.27	0.36	0.10	0.082	0.009	0.008	0.001	0.021	0.026	0.004	0.001	0.007
WAUCOMA / FAYETTE	No.4-3/8	55.36	0.27	0.45	0.12	0.087	0.009	0.009	0.001	0.014	0.033	0.004	0.001	0.006
WEEPING WATER / CASS	1/2-3/4	54.71	0.61	1.62	0.26	0.194	0.013	0.013	0.050	0.172	0.056	0.019	0.028	0.067
WEEPING WATER / CASS	3/8-1/2	53.28	0.48	1.79	0.27	0.783	0.013	0.018	0.295	0.056	0.063	0.015	0.028	0.060
WEEPING WATER / CASS	No.4-3/8	54.76	0.50	1.41	0.22	0.229	0.014	0.016	0.067	0.041	0.046	0.017	0.029	0.065

Appendix B

METHOD OF TEST FOR DETERMINING
THE PORE INDEX OF AGGREGATES

SCOPE

This test method covers the procedure to determine the pore index of aggregates.

PROCEDURE

A. Apparatus

1. Balance – A balance having a capacity of 5000 gm or more and accurate to at least 0.5 gm.
2. An Iowa Pore Index apparatus (see Figures 1 and 2). For the first-time setup of the apparatus, the following steps should be taken: 1) An air line needs to be connected to the primary air regulator on the back of the apparatus. The two air regulators should already be pre-set. The primary air regulator should be set to 65 - 70 psi (gauge on back of apparatus) and the secondary air regulator should be set to 35 psi (gauge on front of instrument). 2) The hose to the three-way valve near the sample pot water inlet needs to be connected to a water source with water at room temperature. 3) A tygon or water hose should be connected to the three-way valve water outlet and run into a drain or sink. 4) The Iowa Pore Index Apparatus should be leveled using the bubble level mounted between the graduated cylinders.
3. Oven – capable of maintaining a uniform temperature of 230$\pm$9° F.
4. Sieves – wooden box sieves of suitable size to get the proper size materials as needed for test.

B. System Check

1. The Pore Index Apparatus should be checked each day of operation by running only water in the sample pot. The results of this check will also be used to determine the amount of sample pot expansion when the system is under pressure (step 6 under Test Procedure). To determine the amount of pot expansion, follow steps 1 through 5 of the Test Procedure. Stop the test after the primary load is determined (after one minute). Take and record the amount of pot expansion from the primary load (first) graduated cylinder. Use this amount in the calculation in step 6 (usually about 40 ml).

C. Test Procedure

1. Place 4500 grams of oven-dried +1/2 -3/4" aggregate in the sample pot. Push on the sample pot lid to snap into place. Place the lever across the top of the sample pot lid and tighten ~~with~~ the threaded clamp to align the two indicator lines. It is important that the sample pot lid is clamped with the same clamp pressure for every test.

2. Make sure that compressed air and water are being supplied to the apparatus.
3. Turn power switch to On and the green power indicator light should come on.
4. Turn the Mode Switch from Off to Load. Push the Start Button and the load indicator light should come on. To regulate the rate of fill to the graduated cylinders on the apparatus, feather the three-way valve on the sample pot to the load position. Carefully fill until water is at the zero mark on all three graduated cylinders and then turn the three-way valve to the Run position. It is very important that the water is at the zero mark on the three graduated cylinders for every test. Failure to do so will affect the accuracy of this test.
5. Turn the Mode Switch clockwise to the Run position and push the Start Button. The run indicator light should come on and the load indicator light will turn off. The valve to the first (primary) graduated cylinder will open and the valves to the second (secondary) and third (system check) graduated cylinders will close. The primary load indicator light will come on and the primary load digital timer will begin. After one minute the primary load indicator light and the primary load digital timer will turn off and the secondary load indicator light and secondary load digital timer will turn on. The secondary graduated cylinder valve will open and the primary graduated cylinder valve will close. After 14 minutes the secondary indicator light and digital timer will turn off and the system check indicator light and digital timer will turn on. The system check graduated cylinder valve will open and the secondary graduated cylinder valve will close. After 15 more minutes, the system check indicator light and digital timer will turn off and the system check graduated cylinder valve will close. After a short delay, the test done light will come on.
6. Take and record readings from all three graduated cylinders (in ml). Use the following equations to determine the primary and secondary pore indexes:

   Primary pore index = (1 minute reading – pot expansion) X (9000 ÷ sample weight)

   Secondary pore index = (14 minute reading) X (9000 ÷ sample weight)
7. Turn the Mode Switch to the Drain position, push the Start Button, and switch the three-way valve on the sample pot to the Drain position. All three graduated cylinder valves will open.
8. After the water has drained, carefully loosen the threaded clamp securing the sample pot lid and allow the air pressure to unseal the sample lid. If necessary, close the drain valve to assist lid removal.
9. Switch the Mode Switch to the Off position. All the digital timers will be reset. Remove sample.

<u>NOTES</u>

1. The secondary pore index number represents the amount of water injected into the aggregate capillary pore system (0.1 to 0.01 micrometer radius). A secondary load of 27 or greater indicates an inability of the aggregate to withstand saturated freeze-thaw pressures.
2. If the system check graduated cylinder does not read less than six after the test, this indicates a leak in the pressurized system and the test is not valid.

3. The Stop Button can be activated at any time. This is the same as turning the Mode Switch to Off. This will open all the graduated cylinder valves, air-source valve will close, the vent valve will open, and the digital timers will be reset.
4. The GFI (ground fault interrupt) on the electric plug will need to be reset if there is any interruption in power. This includes unplugging the power cord.
5. The battery powered digital timers are always lit. Batteries should last 10 years before needing replacement.
6. A faint air noise will be present from the secondary air regulator. This is normal for a precision regulator as it adjusts pressure.
7. If the apparatus is overfilled with water, press Stop and open the small valve located on the lower left front panel.
8. Clean and lubricate (with petroleum jelly) the O-ring in the sample pot lid as needed. IF a replacement O-ring is needed, replace with a No. 267 Buna-N.

Figure 1. Iowa pore index apparatus and control panel.

Figure 2. Control panel with (from right to left) Stop button, Start button, Mode Switch, indicator lights, digital timers, and power switch.

Appendix C

Iowa Pore Index Data Tables

A-Number	Source	beds	Agg Size	Primary	Secondary
A42002	Alden	0,1,3	1/2"	74	10
A42002	Alden	0,1,3	1/2"	78	12
A42002	Alden	0,1,3	1/2"	82	10
A42002	Alden	0,1,3	1/2"	74	10
A42002	Alden	0,1,3	1/2"	72	10
A42002	Alden	0,1,3	1/2"	76	10
A42002	Alden	0,1,3	1/2"	84	12
A42002	Alden	0,1,3	1/2"	80	12
A42002	Alden	0,1,3	1/2"	78	12
A42002	Alden	0,1,3	1/2"	64	10
A42002	Alden	0,1,3	1/2"	68	10
A42002	Alden	0,1,3	3/8"	72	8
A42002	Alden	0,1,3	3/8"	68	8
A42002	Alden	0,1,3	3/8"	72	8
A42002	Alden	0,1,3	3/8"	80	8
A42002	Alden	0,1,3	3/8"	76	8
A42002	Alden	0,1,3	3/8"	80	8
A42002	Alden	0,1,3	3/8"	72	8
A42002	Alden	0,1,3	3/8"	72	8
A42002	Alden	0,1,3	3/8"	72	8
A42002	Alden	0,1,3	3/8"	76	8
A42002	Alden	0,1,3	3/8"	80	8
A42002	Alden	0,1,3	#4	76	8
A42002	Alden	0,1,3	#4	68	6
A42002	Alden	0,1,3	#4	72	6
A42002	Alden	0,1,3	#4	68	6
A42002	Alden	0,1,3	#4	64	6
A42002	Alden	0,1,3	#4	68	6
A42002	Alden	0,1,3	#4	68	6
A42002	Alden	0,1,3	#4	68	6
A42002	Alden	0,1,3	#4	68	6
A42002	Alden	0,1,3	#4	76	6
A42002	Alden	0,1,3	#4	64	6

A-Number	Source	beds	Agg Size	Primary	Secondary
A85006	Ames	47	1/2"	12	14
A85006	Ames	47	1/2"	12	14
A85006	Ames	47	1/2"	12	14
A85006	Ames	47	1/2"	12	12
A85006	Ames	47	1/2"	16	14
A85006	Ames	47	1/2"	12	14
A85006	Ames	47	1/2"	16	14
A85006	Ames	47	1/2"	14	14
A85006	Ames	47	1/2"	12	14
A85006	Ames	47	1/2"	16	12
A85006	Ames	47	1/2"	12	12
A85006	Ames	47	3/8"	12	10
A85006	Ames	47	3/8"	16	10
A85006	Ames	47	3/8"	12	10
A85006	Ames	47	3/8"	12	10
A85006	Ames	47	3/8"	16	10
A85006	Ames	47	3/8"	10	10
A85006	Ames	47	3/8"	12	10
A85006	Ames	47	3/8"	14	10
A85006	Ames	47	3/8"	12	10
A85006	Ames	47	3/8"	14	10
A85006	Ames	47	3/8"	14	10
A85006	Ames	47	#4	18	6
A85006	Ames	47	#4	12	6
A85006	Ames	47	#4	12	6
A85006	Ames	47	#4	14	6
A85006	Ames	47	#4	12	6
A85006	Ames	47	#4	18	6
A85006	Ames	47	#4	18	6
A85006	Ames	47	#4	12	6
A85006	Ames	47	#4	12	6
A85006	Ames	47	#4	12	6
A85006	Ames	47	#4	12	6

A-Number	Source	beds	Agg Size	Primary	Secondary
A23004	Behr	1-2	1/2"	136	20
A23004	Behr	1-2	1/2"	134	22
A23004	Behr	1-2	1/2"	128	22
A23004	Behr	1-2	1/2"	132	22
A23004	Behr	1-2	1/2"	136	20
A23004	Behr	1-2	3/8"	120	18
A23004	Behr	1-2	3/8"	120	18
A23004	Behr	1-2	3/8"	126	18
A23004	Behr	1-2	3/8"	124	18
A23004	Behr	1-2	3/8"	126	18
A23004	Behr	1-2	#4	108	14
A23004	Behr	1-2	#4	104	14
A23004	Behr	1-2	#4	106	16
A23004	Behr	1-2	#4	118	14
A23004	Behr	1-2	#4	118	16

A-Number	Source	beds	Agg Size	Primary	Secondary
A57008	Bowser-Springville	6-7	1/2"	226	8
A57008	Bowser-Springville	6-7	1/2"	228	8
A57008	Bowser-Springville	6-7	1/2"	226	8
A57008	Bowser-Springville	6-7	1/2"	232	8
A57008	Bowser-Springville	6-7	1/2"	232	8
A57008	Bowser-Springville	6-7	3/8"	206	10
A57008	Bowser-Springville	6-7	3/8"	212	10
A57008	Bowser-Springville	6-7	3/8"	208	10
A57008	Bowser-Springville	6-7	3/8"	208	10
A57008	Bowser-Springville	6-7	3/8"	212	10
A57008	Bowser-Springville	6-7	#4	200	14
A57008	Bowser-Springville	6-7	#4	192	12
A57008	Bowser-Springville	6-7	#4	192	14
A57008	Bowser-Springville	6-7	#4	192	14
A57008	Bowser-Springville	6-7	#4	188	14

A-Numbe	Source	beds	Agg Size	Primary	Secondary
A58002	Colombus Junction Mine	16-19	1/2"	200	20
A58002	Colombus Junction Mine	16-19	1/2"	192	20
A58002	Colombus Junction Mine	16-19	1/2"	188	20
A58002	Colombus Junction Mine	16-19	1/2"	192	20
A58002	Colombus Junction Mine	16-19	1/2"	184	20
A58002	Colombus Junction Mine	16-19	3/8"	188	20
A58002	Colombus Junction Mine	16-19	3/8"	184	18
A58002	Colombus Junction Mine	16-19	3/8"	184	18
A58002	Colombus Junction Mine	16-19	3/8"	182	18
A58002	Colombus Junction Mine	16-19	3/8"	178	20
A58002	Colombus Junction Mine	16-19	#4	174	18
A58002	Colombus Junction Mine	16-19	#4	172	18
A58002	Colombus Junction Mine	16-19	#4	168	18
A58002	Colombus Junction Mine	16-19	#4	166	18
A58002	Colombus Junction Mine	16-19	#4	174	18

A-Number	Source	beds	Agg Size	Primary	Secondary
A66002	Duenow	13	1/2"	14	20
A66002	Duenow	13	1/2"	16	22
A66002	Duenow	13	1/2"	16	22
A66002	Duenow	13	1/2"	16	22
A66002	Duenow	13	1/2"	16	22
A66002	Duenow	13	3/8"	16	18
A66002	Duenow	13	3/8"	18	20
A66002	Duenow	13	3/8"	16	20
A66002	Duenow	13	3/8"	18	20
A66002	Duenow	13	3/8"	14	18
A66002	Duenow	13	#4	20	14
A66002	Duenow	13	#4	16	12
A66002	Duenow	13	#4	20	14
A66002	Duenow	13	#4	18	12
A66002	Duenow	13	#4	20	14

A-Number	Source	beds	Agg Size	Primary	Secondary
A45008	Dotzler	7-10A	1/2"	202	12
A45008	Dotzler	7-10A	1/2"	208	12
A45008	Dotzler	7-10A	1/2"	204	10
A45008	Dotzler	7-10A	1/2"	204	10
A45008	Dotzler	7-10A	1/2"	206	12
A45008	Dotzler	7-10A	3/8"	192	10
A45008	Dotzler	7-10A	3/8"	186	10
A45008	Dotzler	7-10A	3/8"	192	10
A45008	Dotzler	7-10A	3/8"	190	10
A45008	Dotzler	7-10A	3/8"	194	10
A45008	Dotzler	7-10A	#4	174	12
A45008	Dotzler	7-10A	#4	176	12
A45008	Dotzler	7-10A	#4	172	12
A45008	Dotzler	7-10A	#4	176	12
A45008	Dotzler	7-10A	#4	176	12

A-Number	Source	beds	Agg Size	Primary	Secondary
A63002	Durham Mine	101	1/2"	144	12
A63002	Durham Mine	101	1/2"	148	12
A63002	Durham Mine	101	1/2"	152	14
A63002	Durham Mine	101	1/2"	146	12
A63002	Durham Mine	101	1/2"	144	10
A63002	Durham Mine	101	3/8"	132	10
A63002	Durham Mine	101	3/8"	136	10
A63002	Durham Mine	101	3/8"	136	10
A63002	Durham Mine	101	3/8"	132	10
A63002	Durham Mine	101	3/8"	136	10
A63002	Durham Mine	101	#4	132	12
A63002	Durham Mine	101	#4	130	12
A63002	Durham Mine	101	#4	128	10
A63002	Durham Mine	101	#4	126	10
A63002	Durham Mine	101	#4	130	10

A-Number	Source	beds	Agg Size	Primary	Secondary
A31006	Dyersville-Sundheim	5-12	1/2"	72	18
A31006	Dyersville-Sundheim	5-12	1/2"	68	16
A31006	Dyersville-Sundheim	5-12	1/2"	68	18
A31006	Dyersville-Sundheim	5-12	1/2"	76	18
A31006	Dyersville-Sundheim	5-12	1/2"	76	18
A31006	Dyersville-Sundheim	5-12	3/8"	64	14
A31006	Dyersville-Sundheim	5-12	3/8"	68	14
A31006	Dyersville-Sundheim	5-12	3/8"	68	14
A31006	Dyersville-Sundheim	5-12	3/8"	72	14
A31006	Dyersville-Sundheim	5-12	3/8"	68	14
A31006	Dyersville-Sundheim	5-12	#4	72	12
A31006	Dyersville-Sundheim	5-12	#4	76	12
A31006	Dyersville-Sundheim	5-12	#4	78	12
A31006	Dyersville-Sundheim	5-12	#4	72	12
A31006	Dyersville-Sundheim	5-12	#4	68	12

A-Number	Source	beds	Agg Size	Primary	Secondary
A23002	Elwood-Yeager	1-2	1/2"	110	12
A23002	Elwood-Yeager	1-2	1/2"	108	10
A23002	Elwood-Yeager	1-2	1/2"	116	12
A23002	Elwood-Yeager	1-2	1/2"	112	10
A23002	Elwood-Yeager	1-2	1/2"	112	12
A23002	Elwood-Yeager	1-2	3/8"	100	10
A23002	Elwood-Yeager	1-2	3/8"	106	10
A23002	Elwood-Yeager	1-2	3/8"	102	10
A23002	Elwood-Yeager	1-2	3/8"	102	10
A23002	Elwood-Yeager	1-2	#4	94	10
A23002	Elwood-Yeager	1-2	#4	98	10
A23002	Elwood-Yeager	1-2	#4	92	8
A23002	Elwood-Yeager	1-2	#4	92	10
A23002	Elwood-Yeager	1-2	#4	92	8

A-Number	Source	beds	Agg Size	Primary	Secondary
A46004	Griffith	1-4	1/2"	40	24
A46004	Griffith	1-4	1/2"	44	22
A46004	Griffith	1-4	1/2"	40	20
A46004	Griffith	1-4	1/2"	40	22
A46004	Griffith	1-4	1/2"	42	22
A46004	Griffith	1-4	3/8"	44	14
A46004	Griffith	1-4	3/8"	40	14
A46004	Griffith	1-4	3/8"	40	14
A46004	Griffith	1-4	3/8"	36	12
A46004	Griffith	1-4	3/8"	40	14
A46004	Griffith	1-4	#4	32	8
A46004	Griffith	1-4	#4	40	8
A46004	Griffith	1-4	#4	36	8
A46004	Griffith	1-4	#4	36	8
A46004	Griffith	1-4	#4	36	8

A-Number	Source	beds	Agg Size	Primary	Secondary
A34018	Jones	1-4	1/2"	24	22
A34018	Jones	1-4	1/2"	24	22
A34018	Jones	1-4	1/2"	24	22
A34018	Jones	1-4	1/2"	24	22
A34018	Jones	1-4	1/2"	24	22
A34018	Jones	1-4	3/8"	28	22
A34018	Jones	1-4	3/8"	26	22
A34018	Jones	1-4	3/8"	28	22
A34018	Jones	1-4	3/8"	28	22
A34018	Jones	1-4	3/8"	28	22
A34018	Jones	1-4	#4	28	18
A34018	Jones	1-4	#4	28	16
A34018	Jones	1-4	#4	28	16
A34018	Jones	1-4	#4	28	16
A34018	Jones	1-4	#4	28	16

A-Number	Source	beds	Agg Size	Primary	Secondary
A34010	Lacosta	1-4	1/2"	16	20
A34010	Lacosta	1-4	1/2"	20	20
A34010	Lacosta	1-4	1/2"	16	20
A34010	Lacosta	1-4	1/2"	16	20
A34010	Lacosta	1-4	1/2"	14	20
A34010	Lacosta	1-4	3/8"	16	18
A34010	Lacosta	1-4	3/8"	16	18
A34010	Lacosta	1-4	3/8"	18	18
A34010	Lacosta	1-4	3/8"	16	18
A34010	Lacosta	1-4	3/8"	16	18
A34010	Lacosta	1-4	#4	16	12
A34010	Lacosta	1-4	#4	16	12
A34010	Lacosta	1-4	#4	16	12
A34010	Lacosta	1-4	#4	16	14
A34010	Lacosta	1-4	#4	20	14

Source	beds	Agg Size	Primary	Secondary
Linwood	27-30b	1/2"	19	8
Linwood	27-30b	1/2"	20	8
Linwood	27-30b	1/2"	22	8
Linwood	27-30b	1/2"	24	10
Linwood	27-30b	1/2"	18	8
Linwood	27-30b	3/8"	20	6
Linwood	27-30b	3/8"	16	6
Linwood	27-30b	3/8"	16	6
Linwood	27-30b	3/8"	20	6
Linwood	27-30b	3/8"	16	6
Linwood	27-30b	#4	16	4
Linwood	27-30b	#4	14	4
Linwood	27-30b	#4	18	4
Linwood	27-30b	#4	16	4
Linwood	27-30b	#4	20	4

A-Number	Source	beds	Agg Size	Primary	Secondary
A07008	Morgan	5	1/2"	116	10
A07008	Morgan	5	1/2"	112	10
A07008	Morgan	5	1/2"	110	10
A07008	Morgan	5	1/2"	112	10
A07008	Morgan	5	1/2"	112	10
A07008	Morgan	5	3/8"	120	10
A07008	Morgan	5	3/8"	112	10
A07008	Morgan	5	3/8"	112	10
A07008	Morgan	5	3/8"	112	10
A07008	Morgan	5	3/8"	112	10
A07008	Morgan	5	#4	124	12
A07008	Morgan	5	#4	116	12
A07008	Morgan	5	#4	120	12
A07008	Morgan	5	#4	116	12
A07008	Morgan	5	#4	126	14

A-Number	Source	beds	Agg Size	Primary	Secondary
A17008	Portland West	1-8	1/2"	28	14
A17008	Portland West	1-8	1/2"	28	14
A17008	Portland West	1-8	1/2"	28	14
A17008	Portland West	1-8	1/2"	26	16
A17008	Portland West	1-8	1/2"	28	14
A17008	Portland West	1-8	3/8"	36	14
A17008	Portland West	1-8	3/8"	32	14
A17008	Portland West	1-8	3/8"	28	14
A17008	Portland West	1-8	3/8"	28	14
A17008	Portland West	1-8	3/8"	28	14
A17008	Portland West	1-8	#4	30	12
A17008	Portland West	1-8	#4	34	12
A17008	Portland West	1-8	#4	32	12
A17008	Portland West	1-8	#4	28	12
A17008	Portland West	1-8	#4	28	12

A-Number	Source	beds	Agg Size	Primary	Secondary
A53016	Stone City	2B-3	1/2"	242	8
A53016	Stone City	2B-3	1/2"	244	8
A53016	Stone City	2B-3	1/2"	246	8
A53016	Stone City	2B-3	1/2"	244	8
A53016	Stone City	2B-3	1/2"	248	8
A53016	Stone City	2B-3	3/8"	228	10
A53016	Stone City	2B-3	3/8"	232	10
A53016	Stone City	2B-3	3/8"	228	10
A53016	Stone City	2B-3	3/8"	230	10
A53016	Stone City	2B-3	3/8"	236	10
A53016	Stone City	2B-3	#4	192	14
A53016	Stone City	2B-3	#4	200	14
A53016	Stone City	2B-3	#4	208	12
A53016	Stone City	2B-3	#4	212	12
A53016	Stone City	2B-3	#4	212	12

A-Number	Source	beds	Agg Size	Primary	Secondary
A50002	Sully	27-30b	1/2"	172	16
A50002	Sully	27-30b	1/2"	178	16
A50002	Sully	27-30b	1/2"	176	16
A50002	Sully	27-30b	1/2"	168	18
A50002	Sully	27-30b	1/2"	168	18
A50002	Sully	27-30b	3/8"	160	16
A50002	Sully	27-30b	3/8"	164	16
A50002	Sully	27-30b	3/8"	164	16
A50002	Sully	27-30b	#4	146	14
A50002	Sully	27-30b	#4	144	14
A50002	Sully	27-30b	#4	148	16
A50002	Sully	27-30b	#4	148	14
A50002	Sully	27-30b	#4	148	16

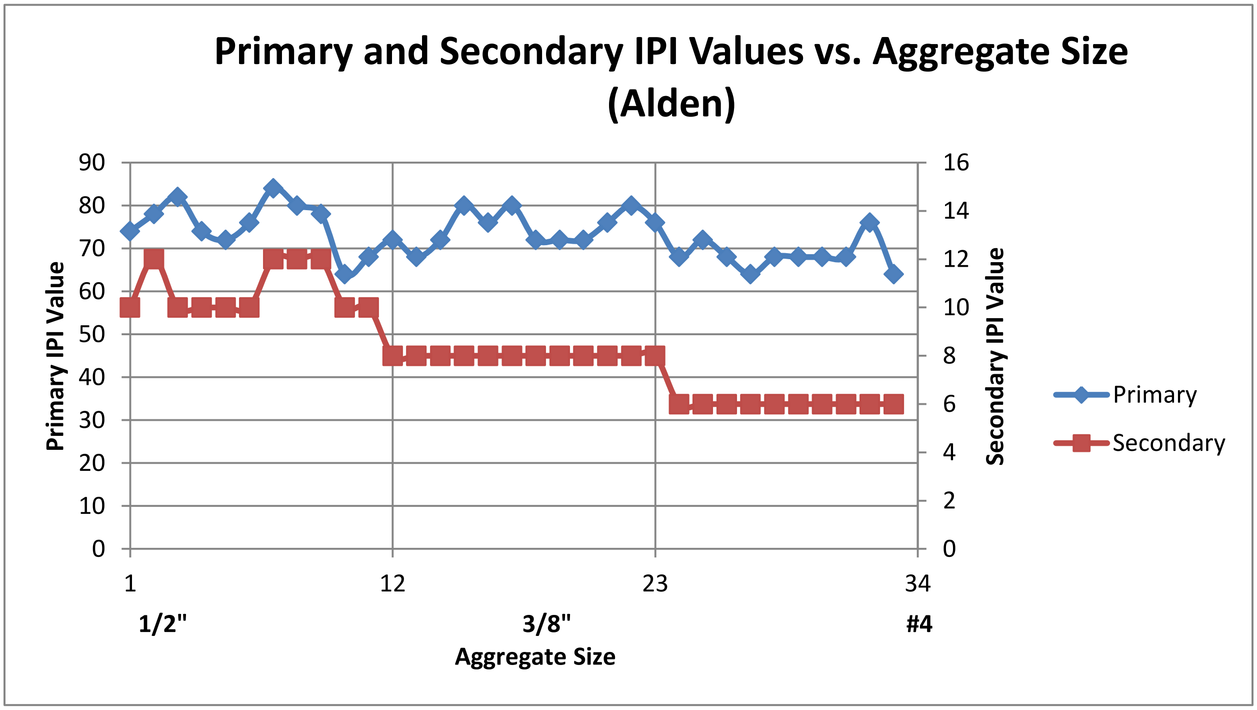
A-Number	Source	beds	Agg Size	Primary	Secondary
A34008	Warnholtz	17-18	1/2"	80	46
A34008	Warnholtz	17-18	1/2"	76	46
A34008	Warnholtz	17-18	1/2"	78	44
A34008	Warnholtz	17-18	1/2"	80	44
A34008	Warnholtz	17-18	1/2"	80	42
A34008	Warnholtz	17-18	3/8"	84	42
A34008	Warnholtz	17-18	3/8"	84	40
A34008	Warnholtz	17-18	3/8"	86	40
A34008	Warnholtz	17-18	3/8"	84	42
A34008	Warnholtz	17-18	3/8"	84	42
A34008	Warnholtz	17-18	#4	88	36
A34008	Warnholtz	17-18	#4	88	36
A34008	Warnholtz	17-18	#4	84	34
A34008	Warnholtz	17-18	#4	88	34
A34008	Warnholtz	17-18	#4	86	32

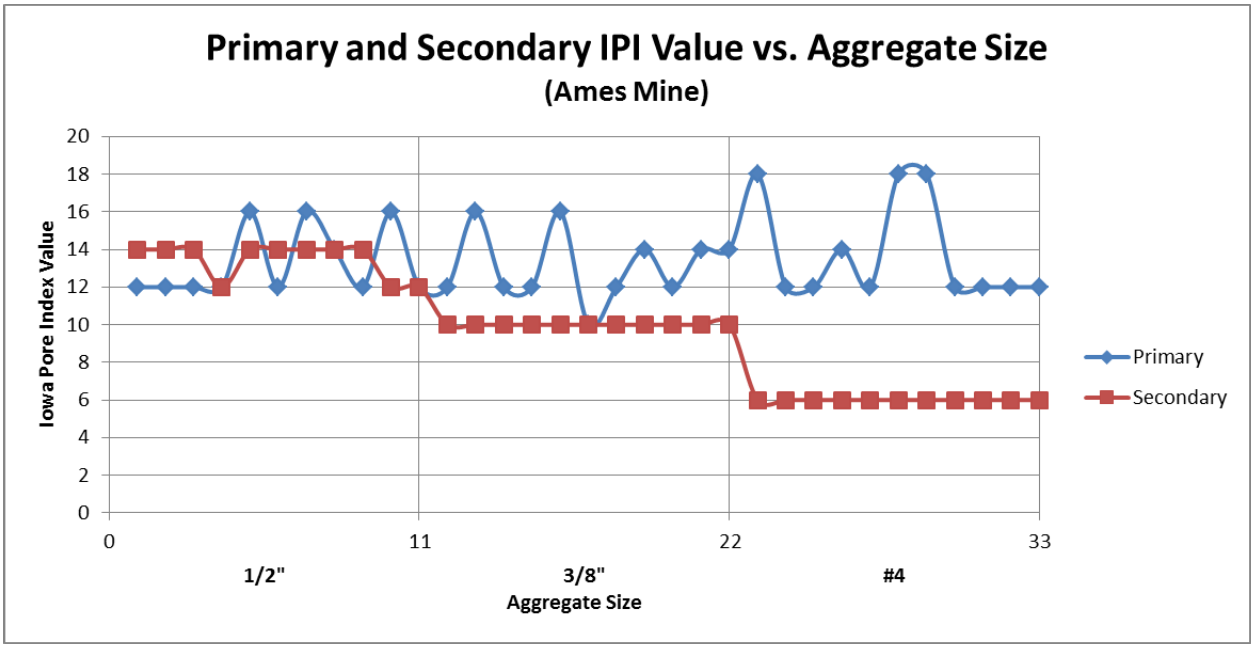
A-Number	Source	beds	Agg Size	Primary	Secondary
A33024	Waucoma	2-5	1/2"	12	10
A33024	Waucoma	2-5	1/2"	12	10
A33024	Waucoma	2-5	1/2"	16	10
A33024	Waucoma	2-5	1/2"	14	10
A33024	Waucoma	2-5	1/2"	14	10
A33024	Waucoma	2-5	3/8"	16	8
A33024	Waucoma	2-5	3/8"	14	8
A33024	Waucoma	2-5	3/8"	14	8
A33024	Waucoma	2-5	3/8"	12	8
A33024	Waucoma	2-5	3/8"	12	8
A33024	Waucoma	2-5	#4	18	8
A33024	Waucoma	2-5	#4	16	6
A33024	Waucoma	2-5	#4	16	8
A33024	Waucoma	2-5	#4	16	6
A33024	Waucoma	2-5	#4	14	6

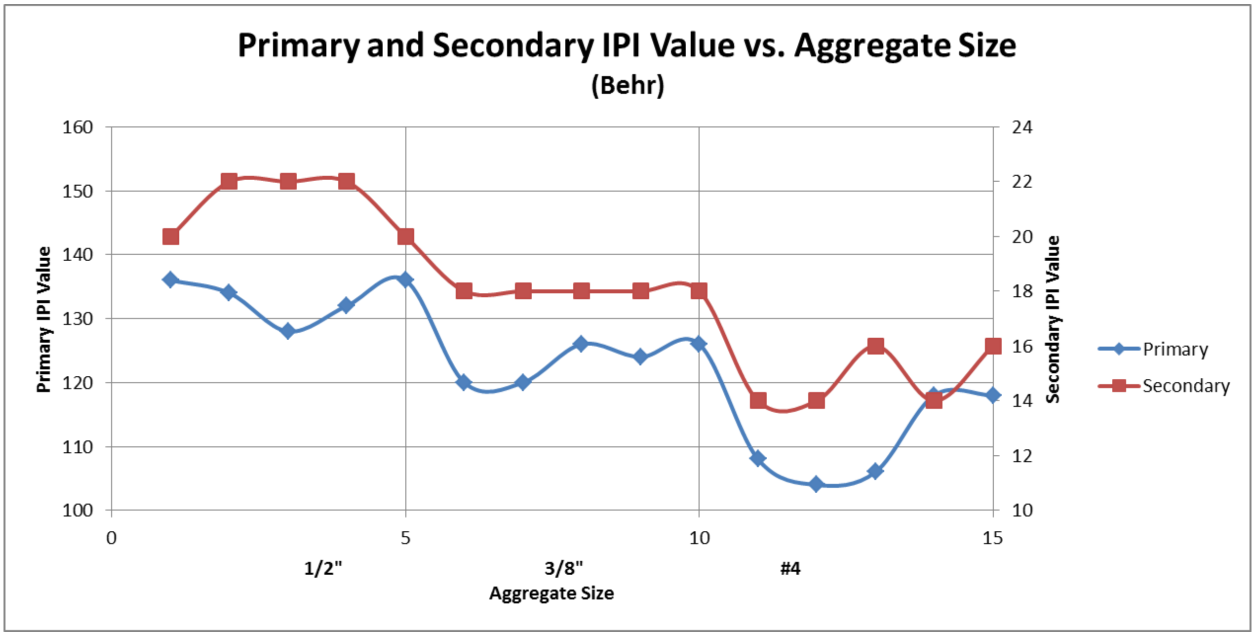
A-Number	Source	beds	Agg Size	Primary	Secondary
ANE002	Weeping Water	9-10b	1/2"	16	20
ANE002	Weeping Water	9-10b	1/2"	16	20
ANE002	Weeping Water	9-10b	1/2"	16	20
ANE002	Weeping Water	9-10b	1/2"	16	20
ANE002	Weeping Water	9-10b	1/2"	14	20
ANE002	Weeping Water	9-10b	3/8"	20	18
ANE002	Weeping Water	9-10b	3/8"	18	18
ANE002	Weeping Water	9-10b	3/8"	20	18
ANE002	Weeping Water	9-10b	3/8"	16	18
ANE002	Weeping Water	9-10b	3/8"	20	18
ANE002	Weeping Water	9-10b	#4	24	14
ANE002	Weeping Water	9-10b	#4	20	14
ANE002	Weeping Water	9-10b	#4	18	14
ANE002	Weeping Water	9-10b	#4	22	14
ANE002	Weeping Water	9-10b	#4	20	14

Appendix D

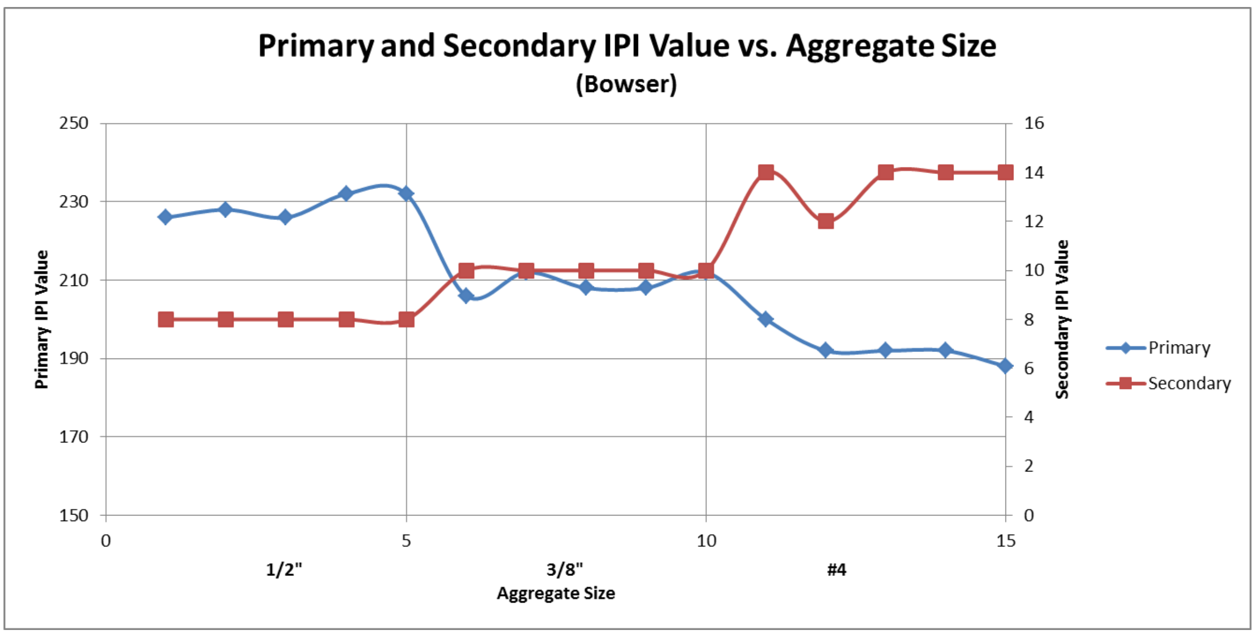
Iowa Pore Index Data Plots



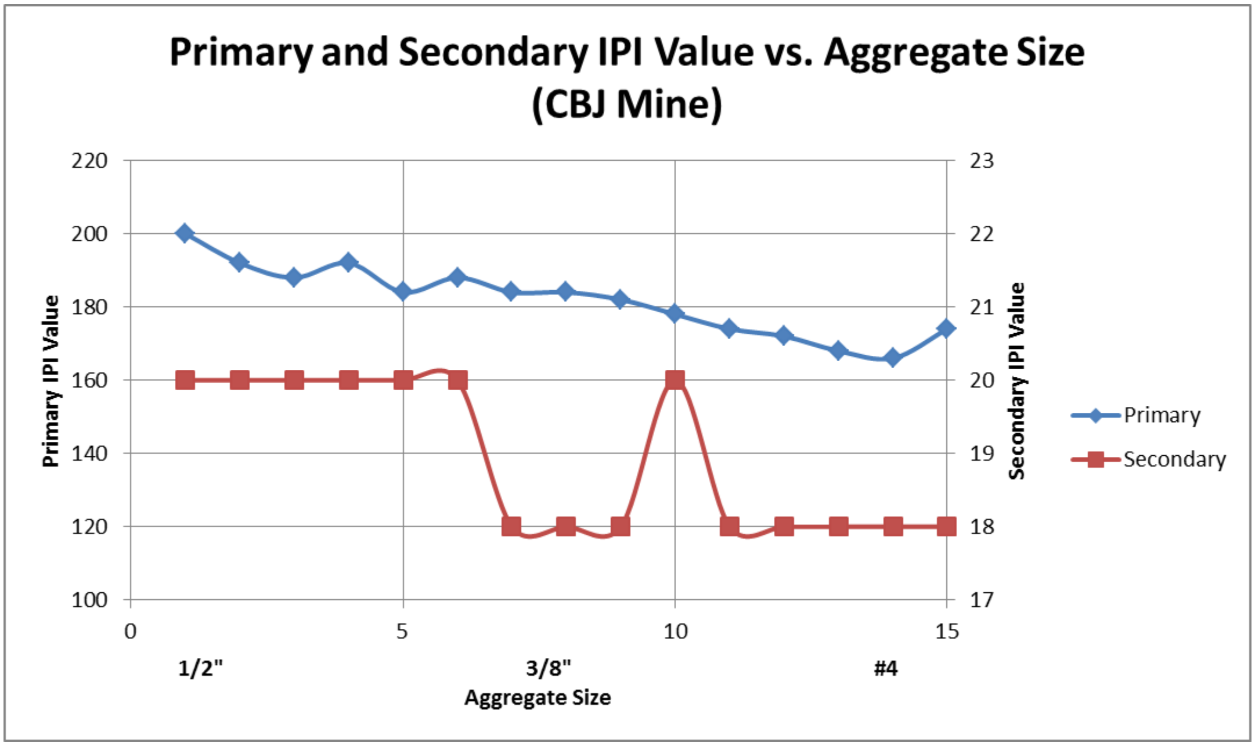


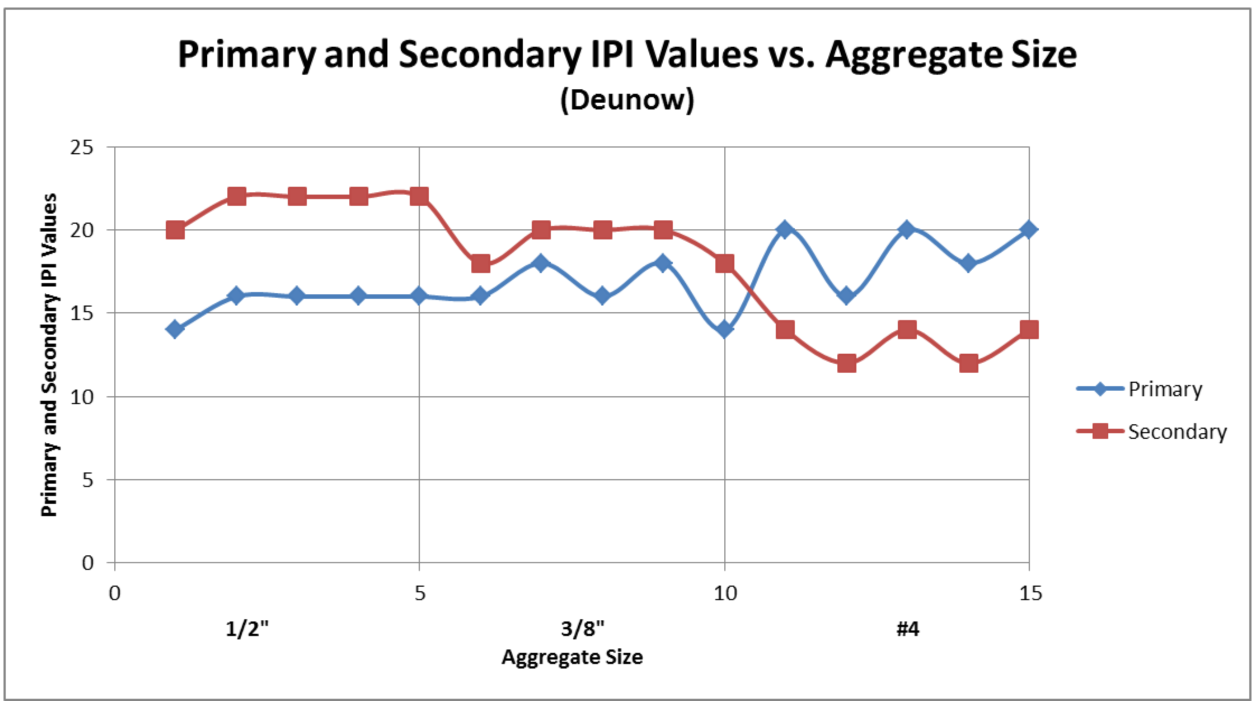


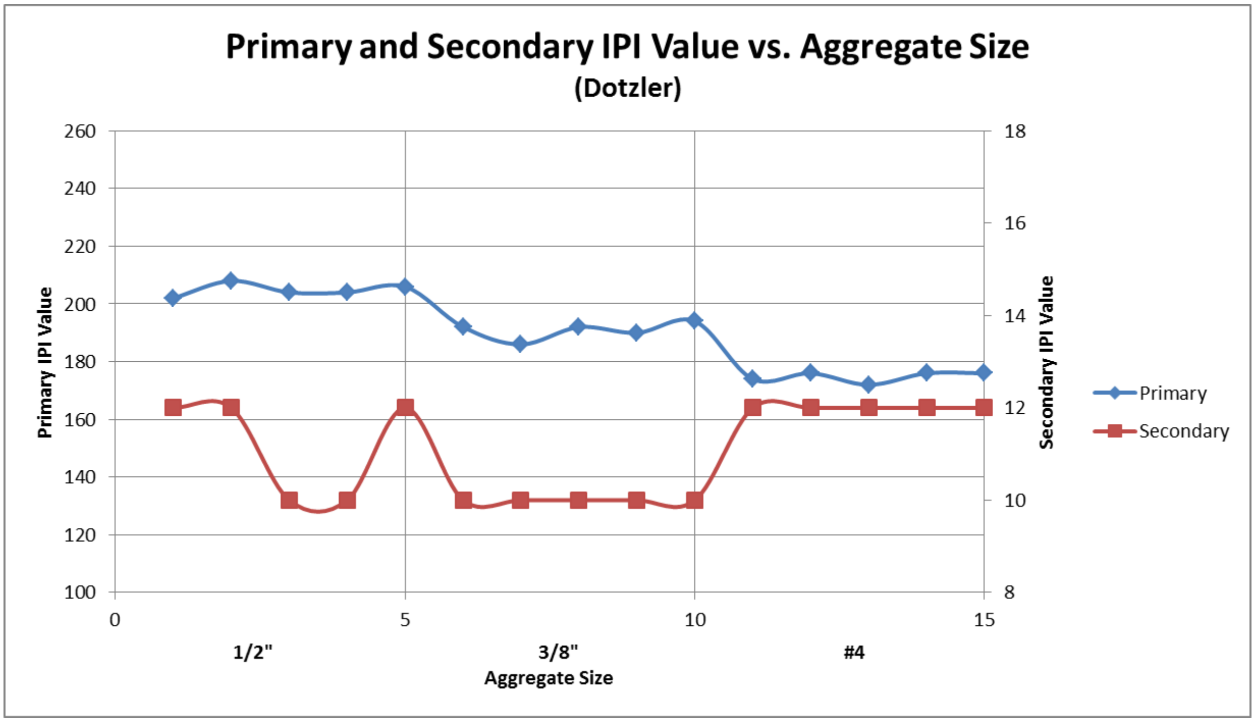
Primary and Secondary IPI Value vs. Aggregate Size
(Behr)
Primary IPI Value
Secondary IPI Value
160
150
140
130
120
110
100
24
22
20
18
16
14
12
10
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary

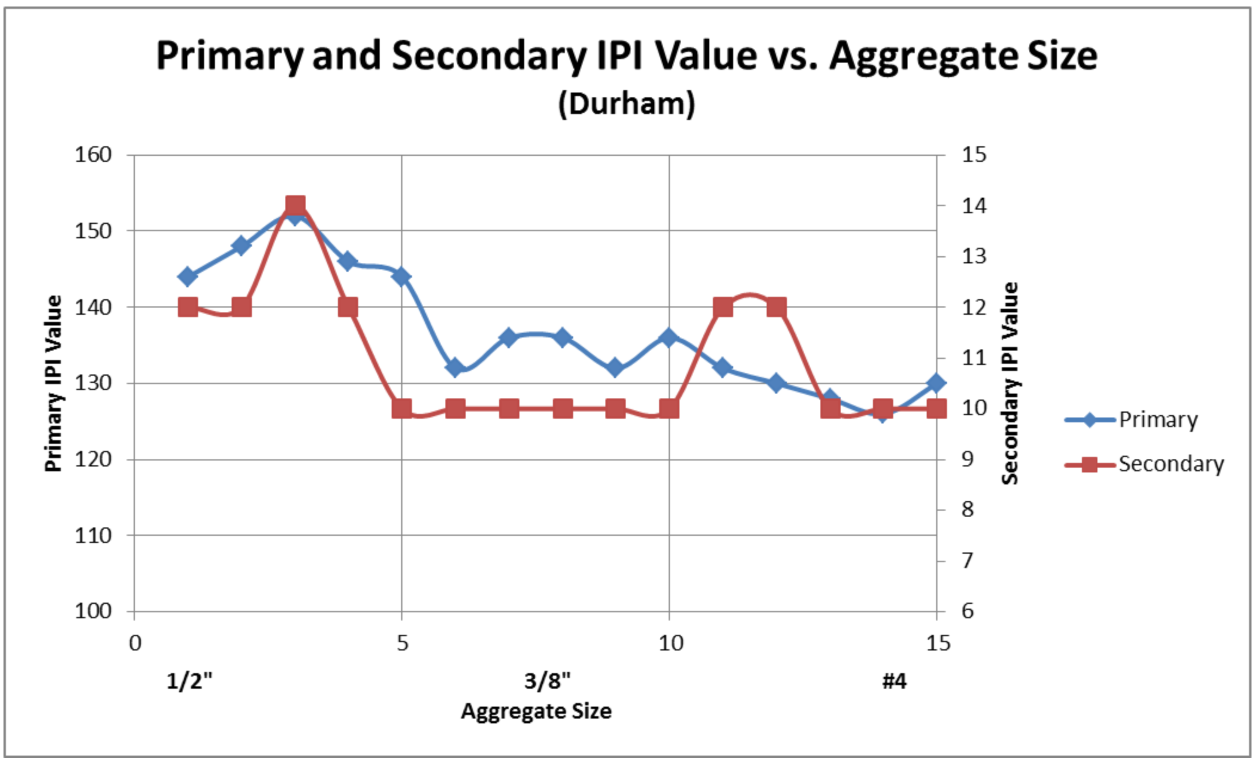


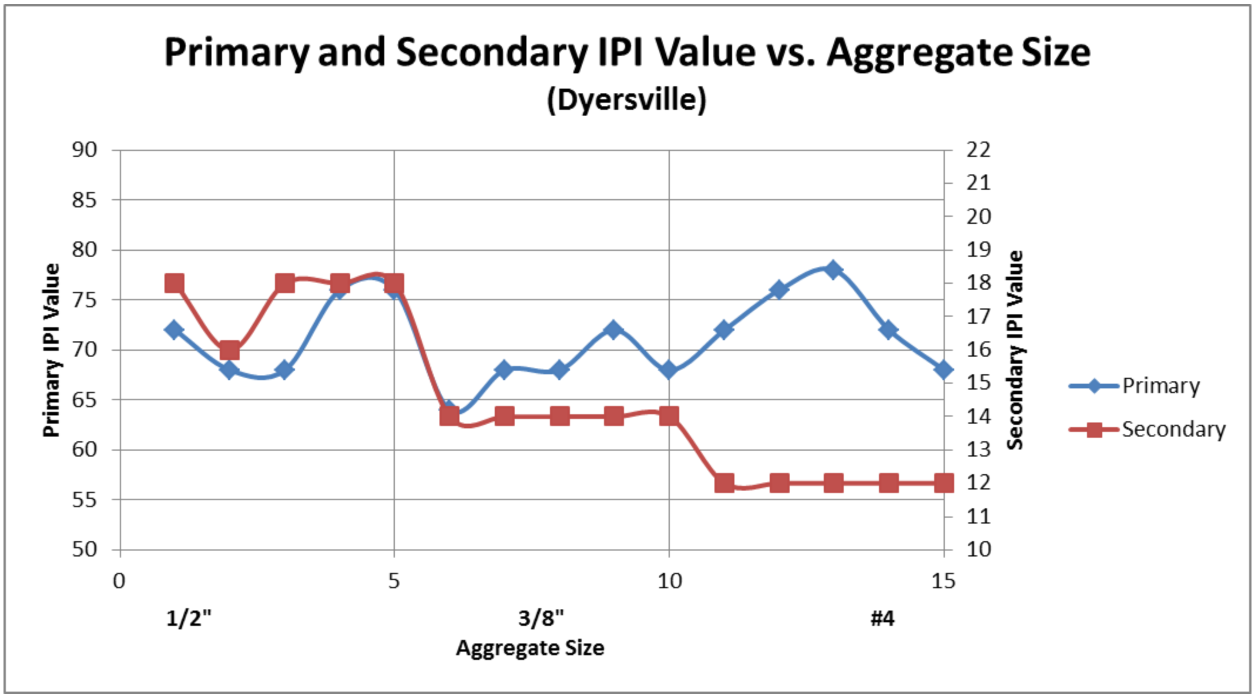
Primary and Secondary IPI Value vs. Aggregate Size
(Bowser)
Primary IPI Value
Secondary IPI Value
250
230
210
190
170
150
16
14
12
10
8
6
4
2
0
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary

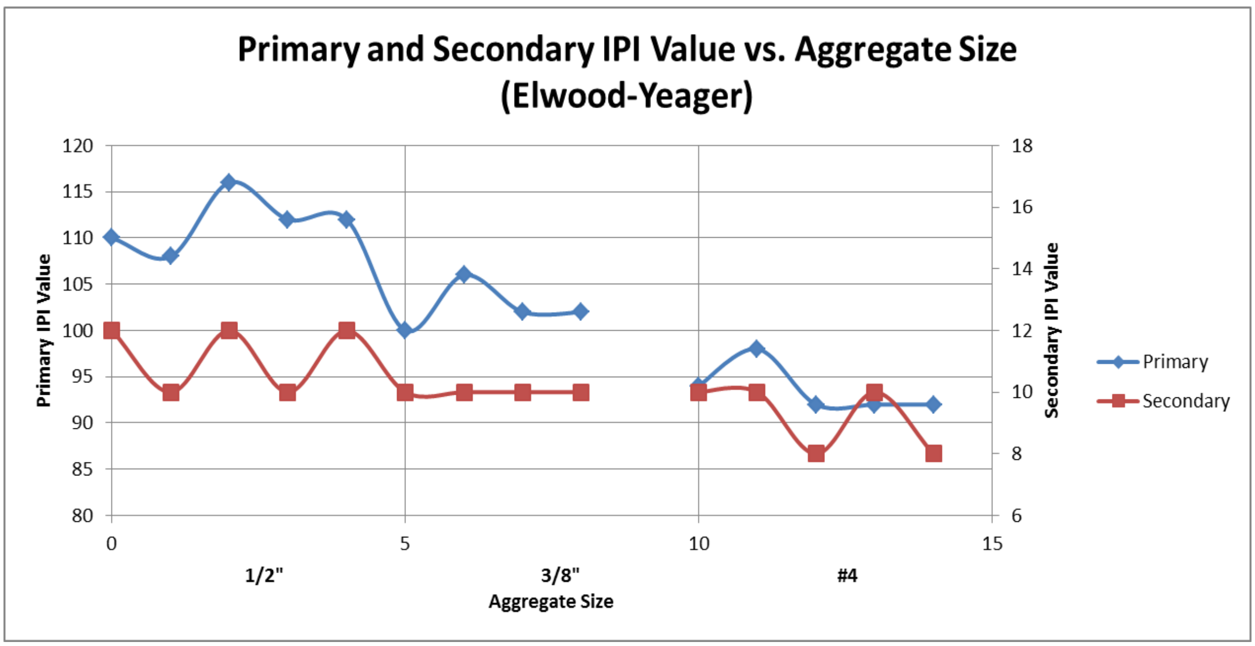

Primary and Secondary IPI Value vs. Aggregate Size
(CBJ Mine)
220
200
180
160
140
120
100
Primary IPI Value
23
22
21
20
19
18
17
Secondary IPI Value
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary

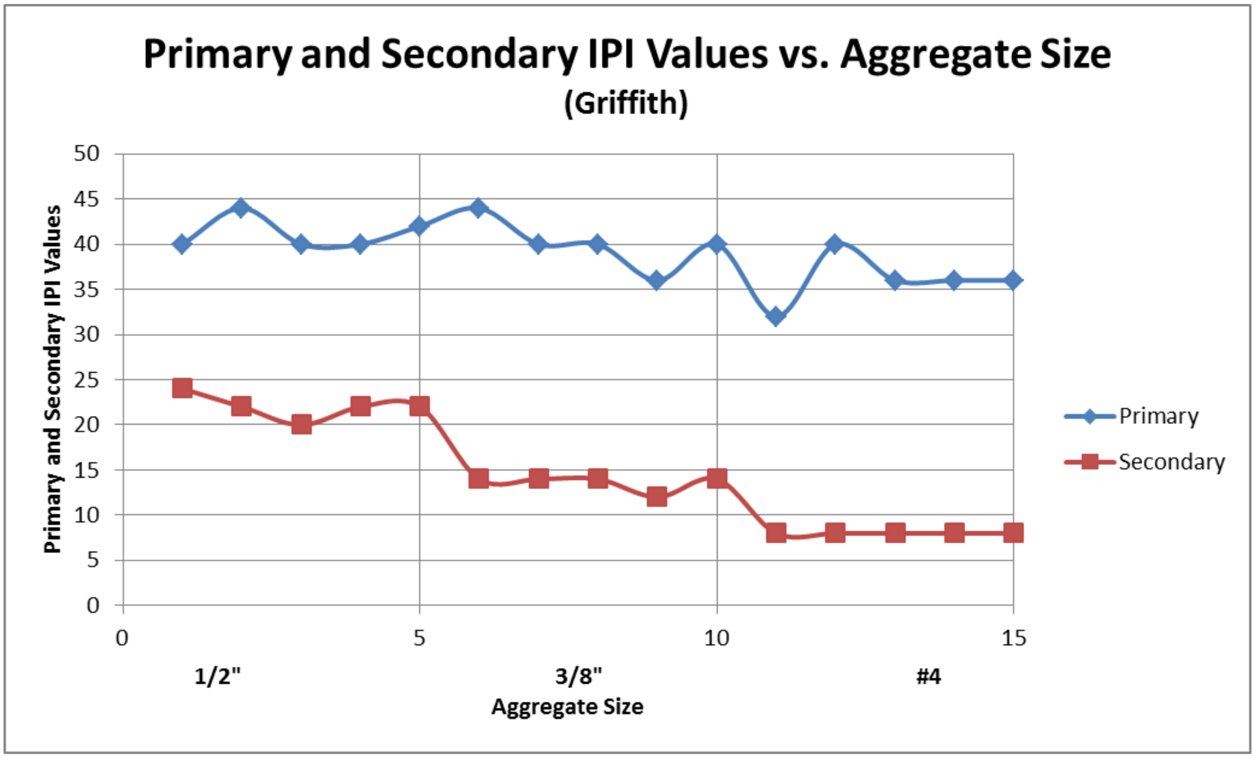

Primary and Secondary IPI Values vs. Aggregate Size
(Deunow)
25
20
15
10
5
0
Primary and Secondary IPI Values
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary

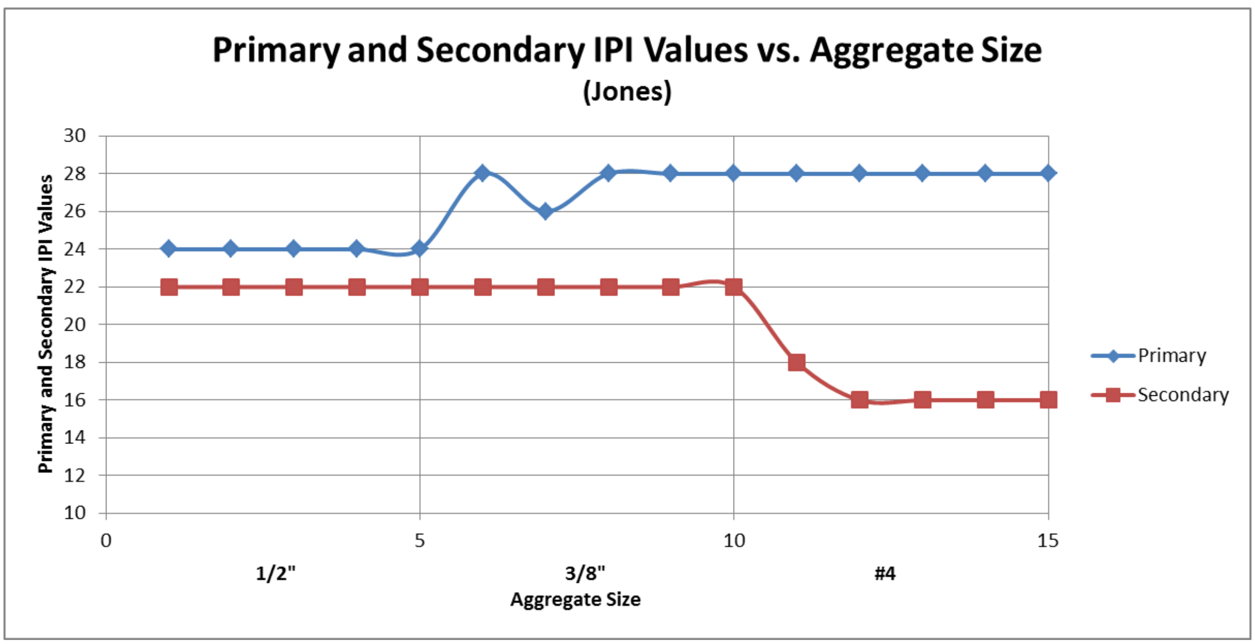

Primary and Secondary IPI Value vs. Aggregate Size
(Dotzler)
Primary IPI Value
Secondary IPI Value
260
240
220
200
180
160
140
120
100
18
16
14
12
10
8
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary

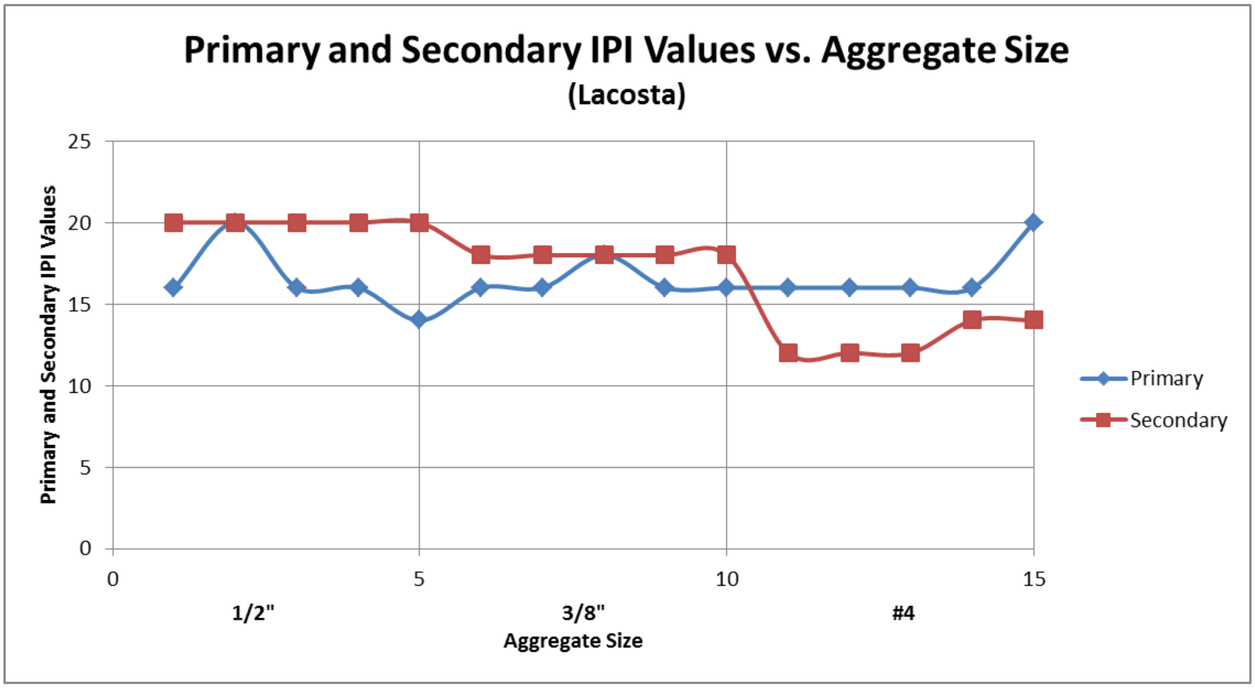

Primary and Secondary IPI Value vs. Aggregate Size
(Durham)
Primary IPI Value
Secondary IPI Value
160
150
140
130
120
110
100
15
14
13
12
11
10
9
8
7
6
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary

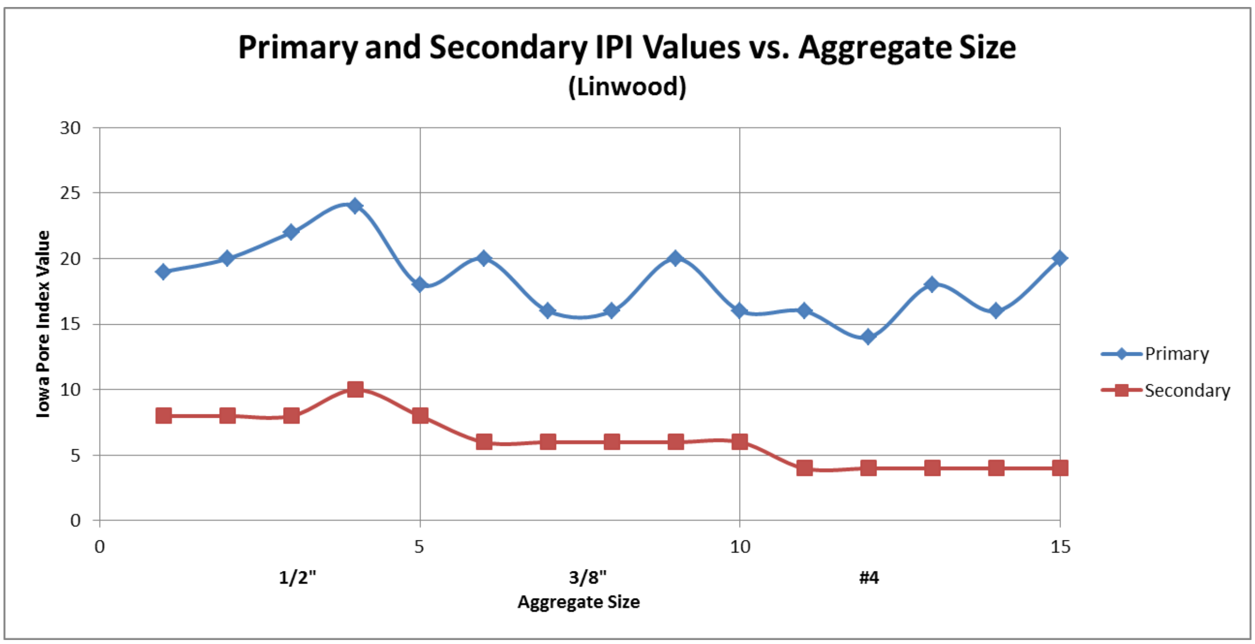

Primary and Secondary IPI Value vs. Aggregate Size
(Dyersville)
Primary IPI Value
Secondary IPI Value
90
85
80
75
70
65
60
55
50
22
21
20
19
18
17
16
15
14
13
12
11
10
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary

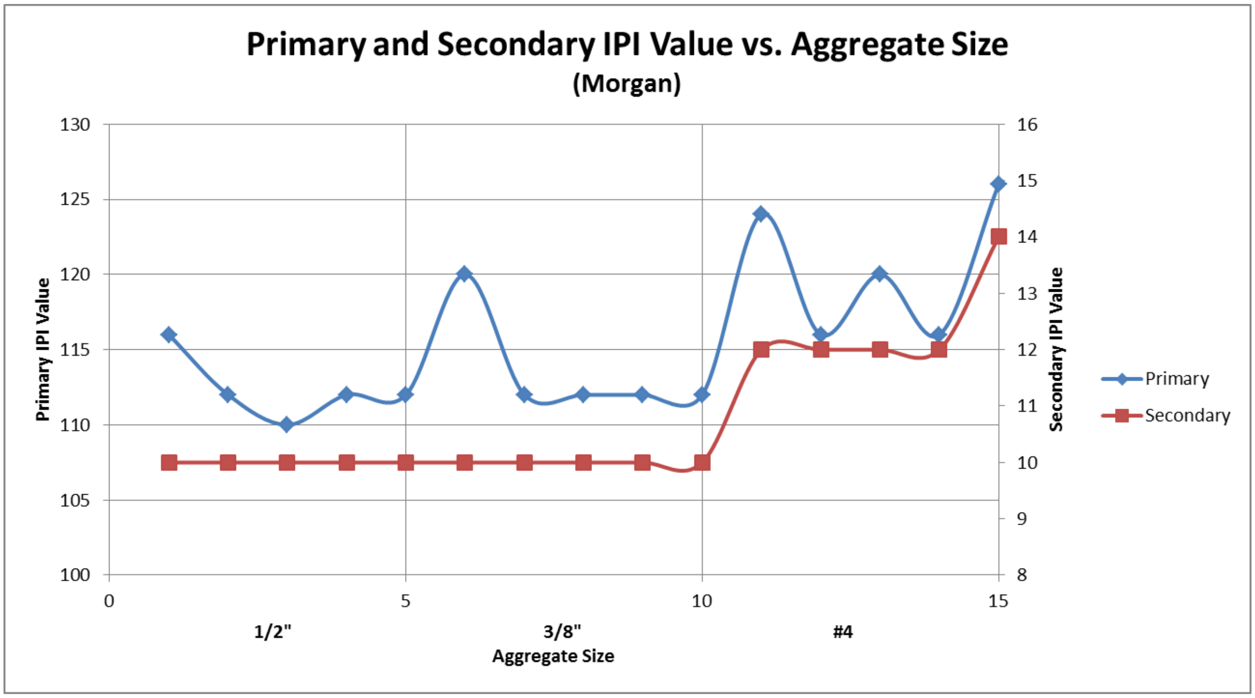

Primary and Secondary IPI Value vs. Aggregate Size
(Elwood-Yeager)
Primary IPI Value
Secondary IPI Value
120
115
110
105
100
95
90
85
80
18
16
14
12
10
8
6
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary


Primary and Secondary IPI Values vs. Aggregate Size
(Griffith)
Primary and Secondary IPI Values
0
5
10
15
20
25
30
35
40
45
50
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary

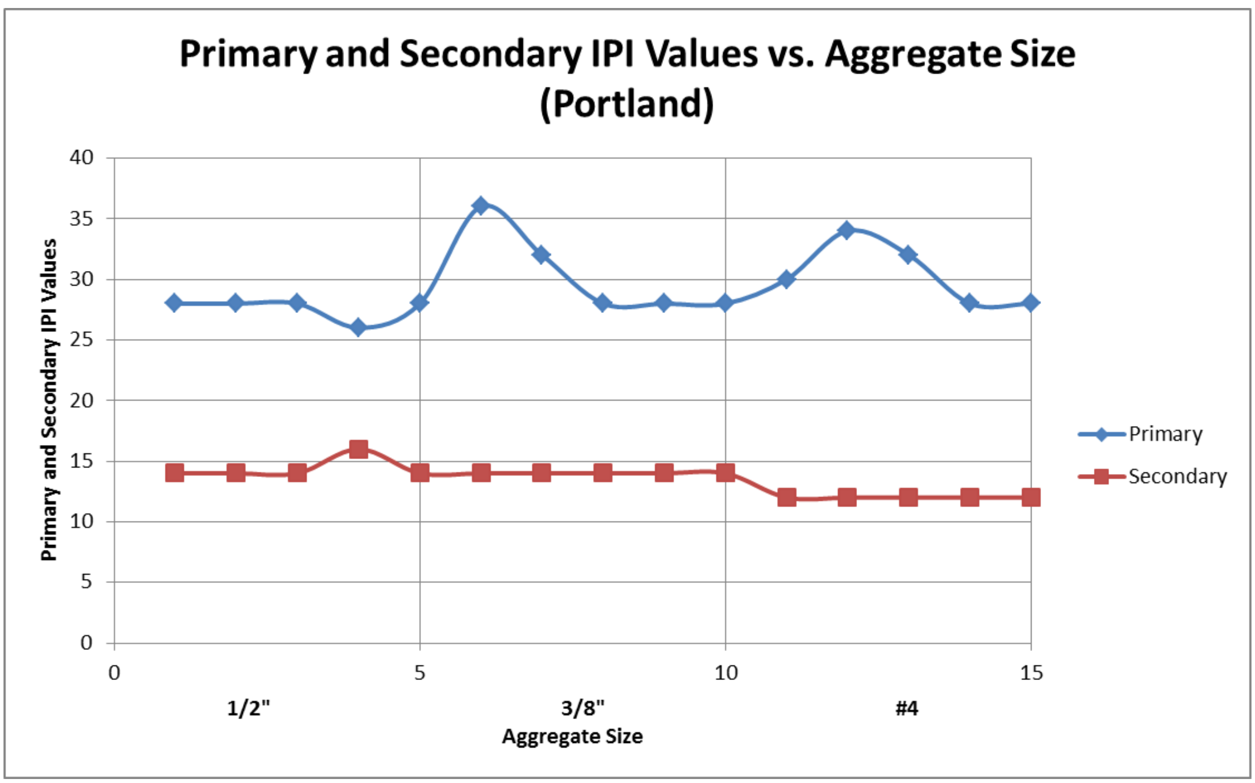

Primary and Secondary IPI Values vs. Aggregate Size
(Jones)
Primary and Secondary IPI Values
10
12
14
16
18
20
22
24
26
28
30
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary


Primary and Secondary IPI Values vs. Aggregate Size
(Lacosta)
Primary and Secondary IPI Values
25
20
15
10
5
0
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary

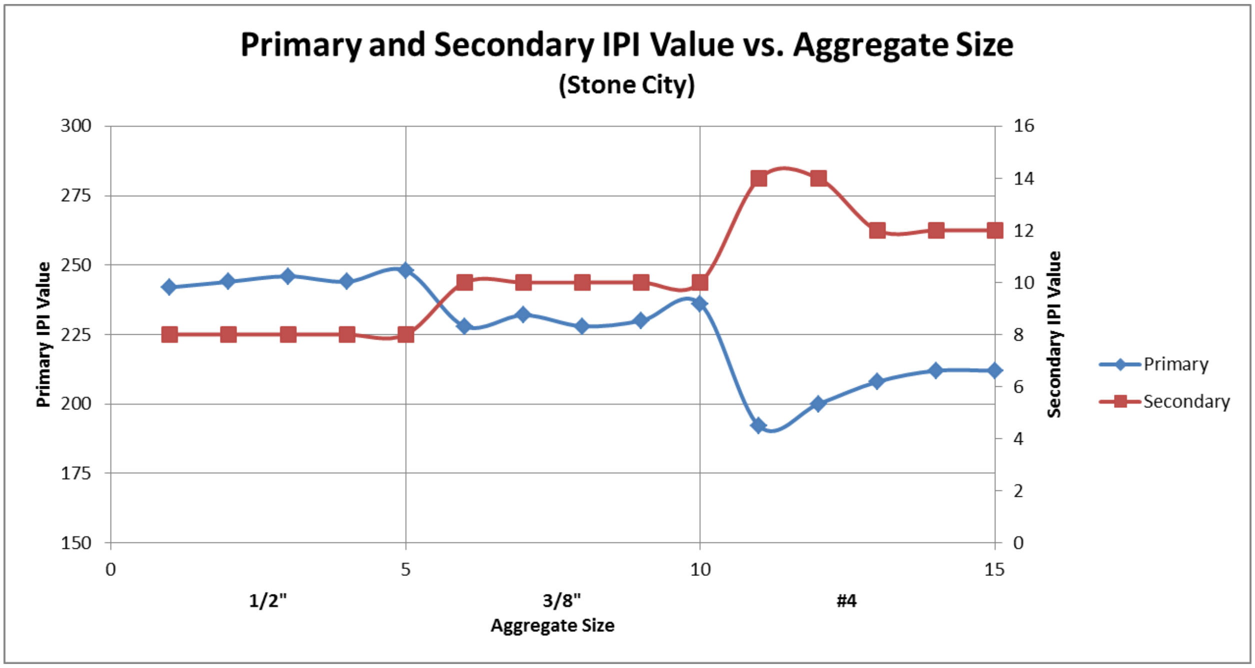

Primary and Secondary IPI Values vs. Aggregate Size
(Linwood)
Iowa Pore Index Value
30
25
20
15
10
5
0
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary

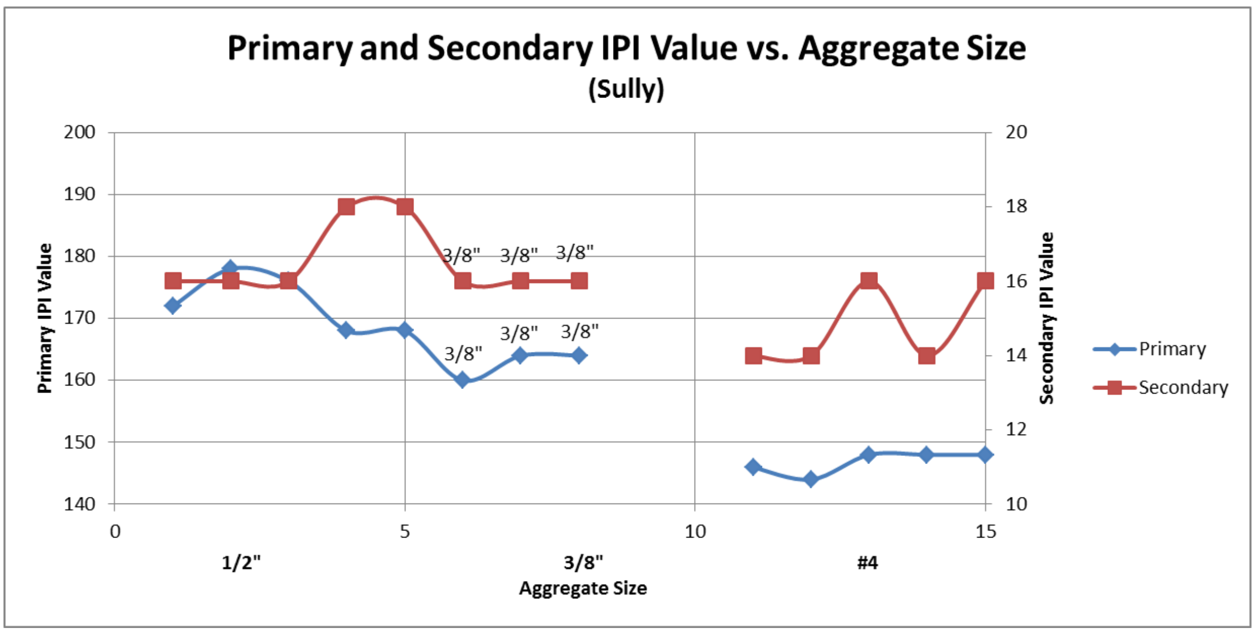


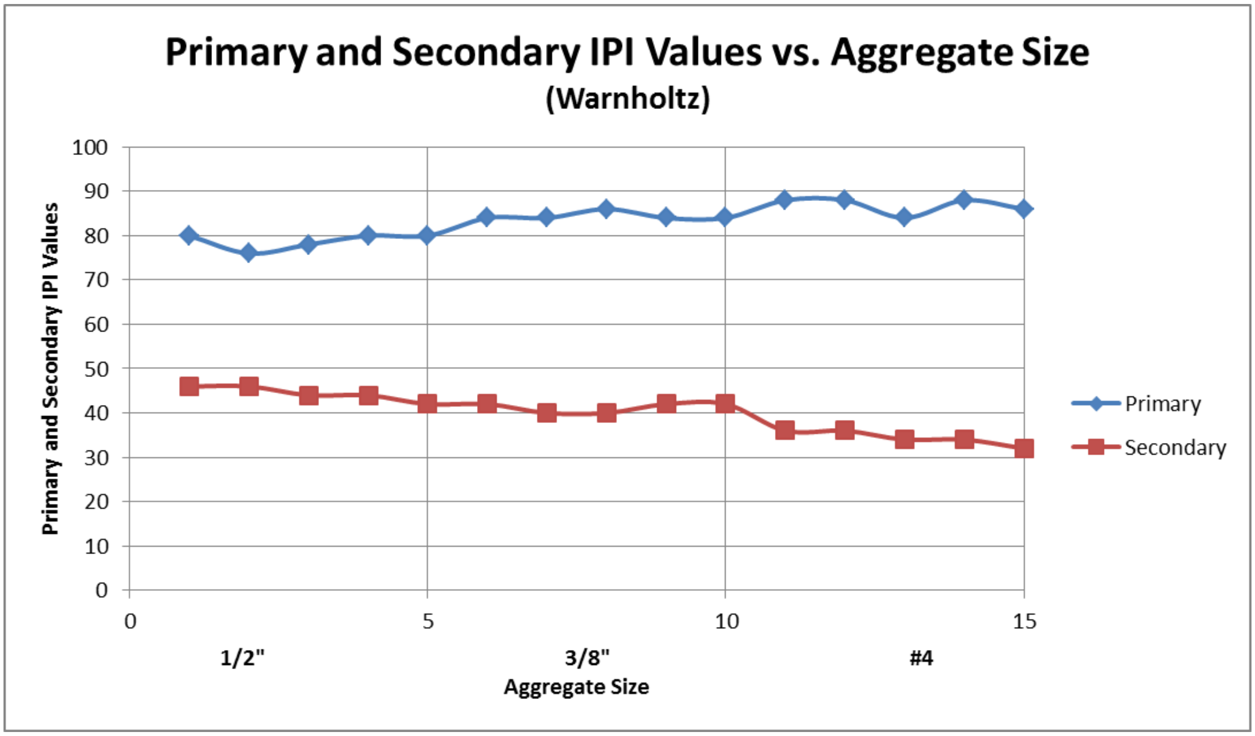
Primary and Secondary IPI Value vs. Aggregate Size
(Morgan)
Primary IPI Value
Secondary IPI Value
130
125
120
115
110
105
100
16
15
14
13
12
11
10
9
8
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary



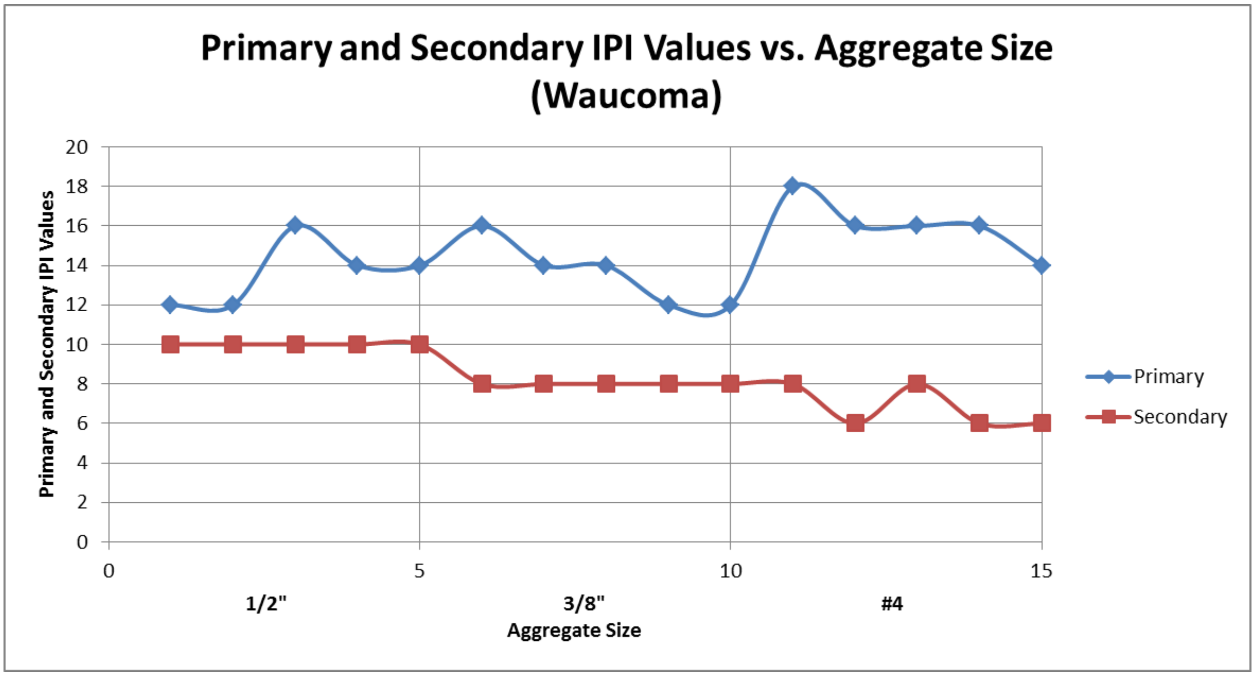
Primary and Secondary IPI Values vs. Aggregate Size
(Portland)
Primary and Secondary IPI Values
40
35
30
25
20
15
10
5
0
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary


Primary and Secondary IPI Value vs. Aggregate Size
(Stone City)
Primary IPI Value
Secondary IPI Value
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary

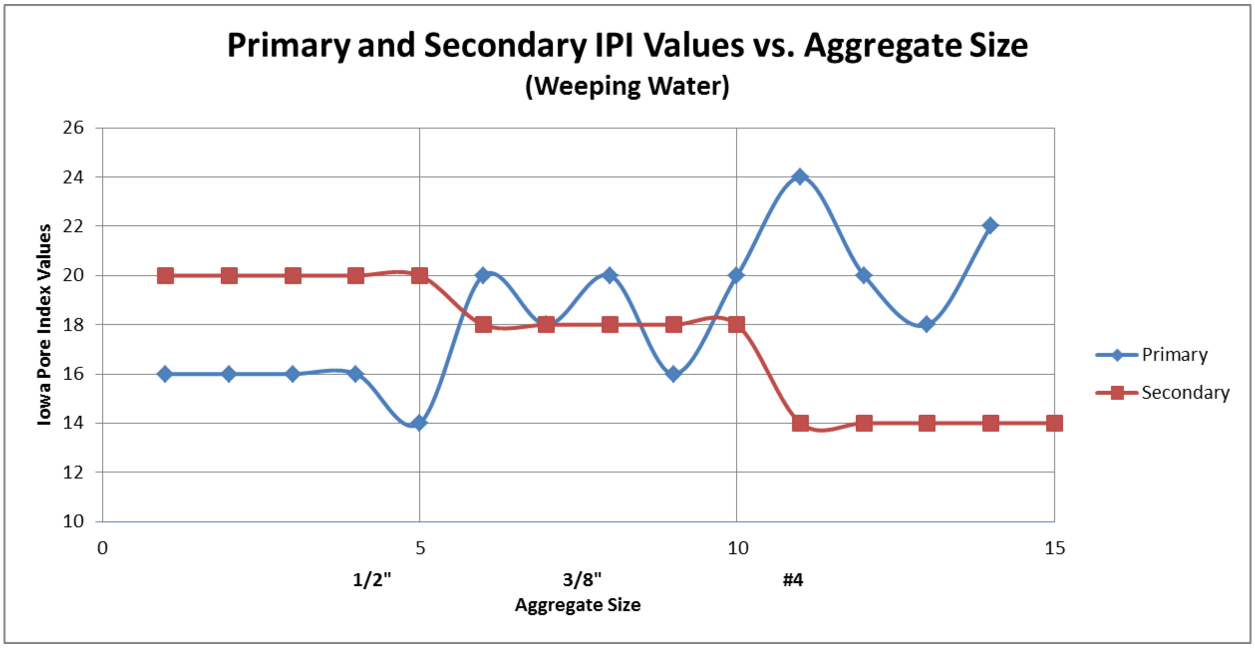

Primary and Secondary IPI Value vs. Aggregate Size
(Sully)
Primary IPI Value
Secondary IPI Value
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary



Primary and Secondary IPI Values vs. Aggregate Size
(Warnholtz)
Primary and Secondary IPI Values
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary



Primary and Secondary IPI Values vs. Aggregate Size
(Waucoma)
Primary and Secondary IPI Values
20
18
16
14
12
10
8
6
4
2
0
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary


Primary and Secondary IPI Values vs. Aggregate Size
(Weeping Water)
Iowa Pore Index Values
26
24
22
20
18
16
14
12
10
0
5
10
15
1/2"
3/8"
#4
Aggregate Size
Primary
Secondary

Appendix E

Standard Deviations and Average IPI Values

Alden		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
75.45	74.55	69.09
Average Secondary IPI Value		
10.73	8.00	6.18
Primary IPI Standard Deviation		
5.66	3.92	3.85
Secondary IPI Standard Deviation		
0.96	0.00	0.57

Ames Mine		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
13.27	13.09	13.82
Average Secondary IPI Value		
13.45	10.00	6.00
Primary IPI Standard Deviation		
1.76	1.78	2.62
Secondary IPI Standard Deviation		
0.89	0.00	0.00

Behr		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
133.20	123.20	110.80
Average Secondary IPI Value		
21.20	18.00	14.80
Primary IPI Standard Deviation		
2.99	2.71	6.01
Secondary IPI Standard Deviation		
0.98	0.00	0.98

Bowser-Springville		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
228.80	209.20	192.80
Average Secondary IPI Value		
8.00	10.00	13.60
Primary IPI Standard Deviation		
2.71	2.40	3.92
Secondary IPI Standard Deviation		
0.00	0.00	0.80

Dotzler		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
204.80	190.80	174.80
Average Secondary IPI Value		
11.20	10.00	12.00
Primary IPI Standard Deviation		
2.04	2.71	1.60
Secondary IPI Standard Deviation		
0.98	0.00	0.00

Colombus Junction Mine		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
191.20	183.20	170.80
Average Secondary IPI Value		
20.00	18.80	18.00
Primary IPI Standard Deviation		
5.31	3.25	3.25
Secondary IPI Standard Deviation		
0.00	0.98	0.00

Durham Mine		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
146.80	134.40	129.20
Average Secondary IPI Value		
12.00	10.00	10.80
Primary IPI Standard Deviation		
2.99	1.96	2.04
Secondary IPI Standard Deviation		
1.26	0.00	0.98

Deunow		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
15.60	16.40	18.80
Average Secondary IPI Value		
21.60	19.20	13.20
Primary IPI Standard Deviation		
0.80	1.50	1.60
Secondary IPI Standard Deviation		
0.80	0.98	0.98

Dyersville-Sundheim		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
72.00	68.00	73.20
Average Secondary IPI Value		
17.60	14.00	12.00
Primary IPI Standard Deviation		
3.58	2.53	3.49
Secondary IPI Standard Deviation		
0.80	0.00	0.00

Elwood-Yeager		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
111.60	102.50	4.60
Average Secondary IPI Value		
11.20	10.00	9.20
Standard Deviation (Primary)		
2.65	2.18	2.33
Standard Deviation (Secondary)		
0.98	0.00	2.33

Lacosta		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
16.40	16.40	16.80
Average Secondary IPI Value		
20.00	18.00	12.80
Primary IPI Standard Deviation		
1.96	0.80	1.60
Secondary IPI Standard Deviation		
0.00	0.00	0.98

Griffith		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
41.20	40.00	8.00
Average Secondary IPI Value		
22.00	13.60	8.00
Primary IPI Standard Deviation		
1.60	2.53	2.53
Secondary IPI Standard Deviation		
1.26	0.80	0.00

Linwood		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
20.60	17.60	16.80
Average Secondary IPI Value		
8.40	6.00	4.00
Primary IPI Standard Deviation		
2.15	1.96	2.04
Secondary IPI Standard Deviation		
0.80	0.00	0.00

Jones		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
24.00	27.60	28.00
Average Secondary IPI Value		
22.00	22.00	16.40
Primary IPI Standard Deviation		
0.00	0.80	0.00
Secondary IPI Standard Deviation		
0.00	0.00	0.80

Morgan		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
112.40	113.60	120.40
Average Secondary IPI Value		
10.00	10.00	12.40
Primary IPI Standard Deviation		
1.96	3.20	4.08
Secondary IPI Standard Deviation		
0.00	0.00	0.80

Portland West		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
27.60	30.40	30.40
Average Secondary IPI Value		
14.40	14.00	12.00
Primary IPI Standard Deviation		
0.80	3.20	2.33
Secondary IPI Standard Deviation		
0.80	0.00	0.00

Warnholtz		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
78.80	84.40	86.80
Average Secondary IPI Value		
44.40	41.20	34.40
Primary IPI Standard Deviation		
1.60	0.80	1.60
Secondary IPI Standard Deviation		
1.50	0.98	1.50

Stone City		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
244.80	230.80	204.80
Average Secondary IPI Value		
8.00	10.00	12.80
Primary IPI Standard Deviation		
2.04	2.99	7.76
Secondary IPI Standard Deviation		
0.00	0.00	0.98

Waucoma		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
13.60	13.60	16.00
Average Secondary IPI Value		
10.00	8.00	6.80
Primary IPI Standard Deviation		
1.50	1.50	1.26
Secondary IPI Standard Deviation		
0.00	0.00	0.98

Sully		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
172.40	162.67	146.80
Average Secondary IPI Value		
16.80	16.00	14.80
Primary IPI Standard Deviation		
4.08	1.89	1.60
Secondary IPI Standard Deviation		
0.98	0.00	0.98

Weeping Water		
1/2-3/4"	3/8-1/2"	#4-3/8"
Average Primary IPI Value		
15.60	18.80	20.80
Average Secondary IPI Value		
20.00	18.00	14.00
Primary IPI Standard Deviation		
0.80	1.60	2.04
Secondary IPI Standard Deviation		
0.00	0.00	0.00