Using ArcGIS to Identify Hog Farms that Pose a Risk to Cause Eutrophication in the Neuse River Basin

Nolan Kirkwood
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Neuse River Basin Location

<u>Introduction</u>

Eutrophication was first defined by SW Nixon in his 1995 article, *Coastal Marine Eutrophication – A Definition, Social Causes, and Future Concerns*. Nixon defines eutrophication as "an increase in the rate of supply of organic matter to an ecosystem." Organic matter flowing into rivers and estuaries is often rich in nutrients such as nitrogen and phosphorus. Both of these nutrients are usually the nutrients that are responsible for limiting the growth of algae in coastal water (Paerl). Coastal regions of the world support about 75% of the people on earth and are immensely important to many biogeochemical cycles (Paerl). When nitrogen and phosphorus levels become elevated, primary production, in the form of algae, can reach extremely high levels and create what are called "algal blooms." These algal blooms can go on to cause toxic, harmful algal blooms, hypoxia, and kill events of marine animals (Paerl).

In the Neuse River Watershed specifically, the ecosystem faces increased pressure from a growing population in the state of North Carolina and the systems of agriculture employed in the region (Census.gov). According to the US census Bureau, the population of North Carolina increased by 3.3% between April, 2010 and July, 2013. More people in the state will lead to more development, and development generally reduces the permeability of land in the state. However, agriculture is one of the largest contributing factors the nitrogen loading in the Neuse River Basin (Paerl). This paper will focus in particular on the risks posed by hog waste lagoons located at swine farms within the Neuse River Basin.

<u>Data</u>

Data for this analysis were collected from a variety of publicly-available sources. North Carolina OneMap was an important source of state-specific information. This was the source of the Animal Operations Permits as well as the spatial extent of the Neuse River Watershed (nconemap.com). Nationally-available data were used from the National Elevation Dataset and the National Land Cover Database.

The data for locating animal operations and determining the type of animal being raised were the most critical for the success of this analysis and were obtained from NC OneMap in the product titled *DENR DWR Animal Operations*. The data were published in 2014 and were created by the North Carolina Department of Energy and Natural Resources Department of Water Resources. The product contained the geographic coordinates of the operation, the permit number, number and type of animals raised at the location, as well as more general information about where the farm is located in the state. The most important pieces of information from this product were the permit numbers, the type of animals, and the count of animals.

The product titled, *North Carolina River Basins*, available from NC OneMap, provides the names and locations of the HUC6 regions in North Carolina. Once downloaded, the Neuse River basin was selected out of the rest of the data to be used in the project. The data were published in 2013 by the North Carolina Natural Resources Conservation Service.

The National Elevation Dataset and the National Land Cover Database are both freely-available US Geological Survey products that provide coverage for the entire country. NED

provides elevation at a 30m resolution for the nation. NLCD divides the country into 16

different classes at a 30m resolution. In addition to land cover type, the NLCD provides the

percent permeability of the ground at a location, which was important in determining risk from

hog farms.

Methods

The first step of this project was to create a display, using the "clip" tool, which selected

only the animal operations that were contained inside the Neuse River Basin and the NED data

inside the basin. Then to select the swine operations out of all of the animal operations in the

basin. Setting the symbology to a color-coded display based on the COUNT feature created

figure 1. This will allow for the operations with more animals to be classified as being more risk-

prone.
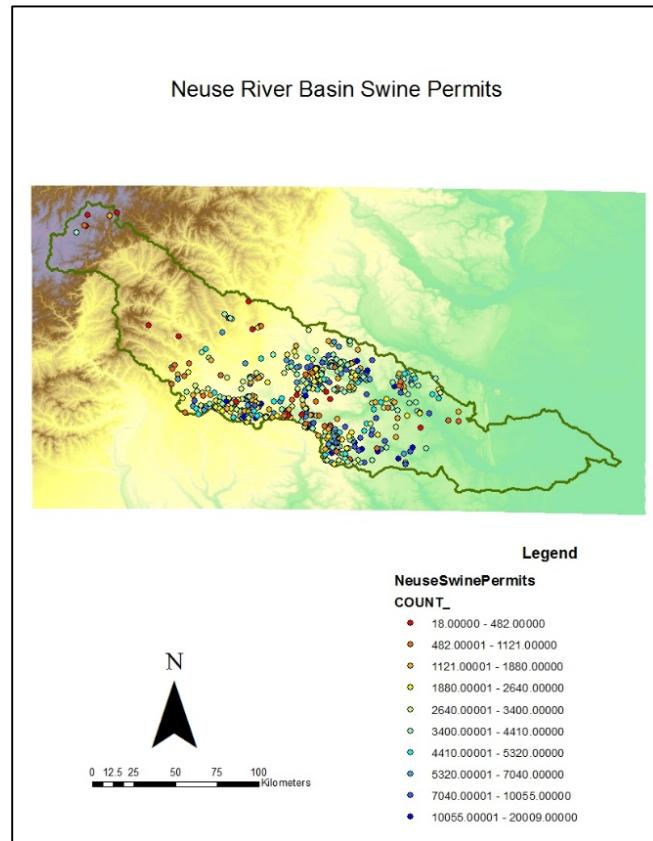
Figure 1

The TauDEM toolset was the next element of the project. The ultimate goal of this step

was to create a layer of rivers to be used in the TauDEM tool "D-Infinity Distance Down." In

order to create the stream layer, a series of steps needed to be followed. The steps progressed

just like the delineation of any watershed, first the pits needed to be filled ad the flow direction

calculated. Once the direction was calculated, the contributing area can be determined. The

contributing area is simply the number of cells that flow to any given cell. The contributing area

is a key factor in determining the location of streams in the watershed. Figure 2 illustrates the

three layers created in these three steps. The noisiness in the flow direction, and the lack of any

clear patterns in the flow accumulation are likely to do the extremely flat topography of Eastern

North Carolina.
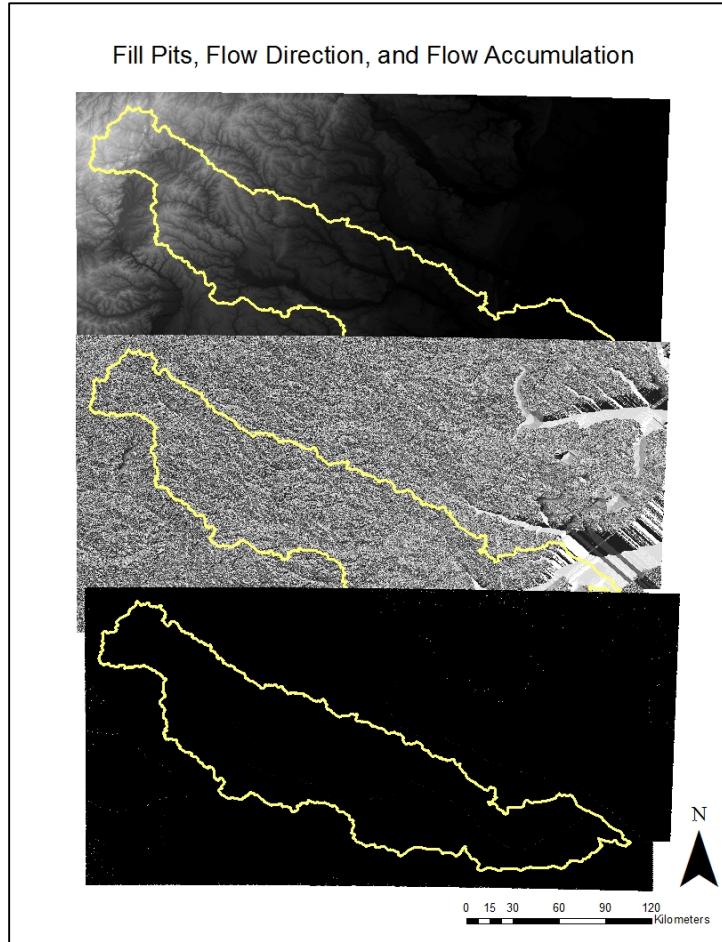
Figure 2

After setting all of these parameters, it is possible to define the streams using TauDEM's "Stream Definition by Threshold" tool. The tool uses the filled DEM, and flow accumulation to determine streams based on a threshold of contributing cells set by the user. In this case, I tested a few different threshold values (100 cells, 250 cells, 500 cells) before settling on 750 contributing cells being the defining factor for what was considered a stream. Using the the National Hydrography Dataset as a point of comparison, the 750 cell threshold seemed to best replicate the accepted locations of streams in the river basin. The comparison can be seen in figure 3, where I have zoomed in on the area surrounding the Cliffs of the Neuse State Park to illustrate how the two layers compare. As you can see, it isn't a perfect match, but will work for this application.
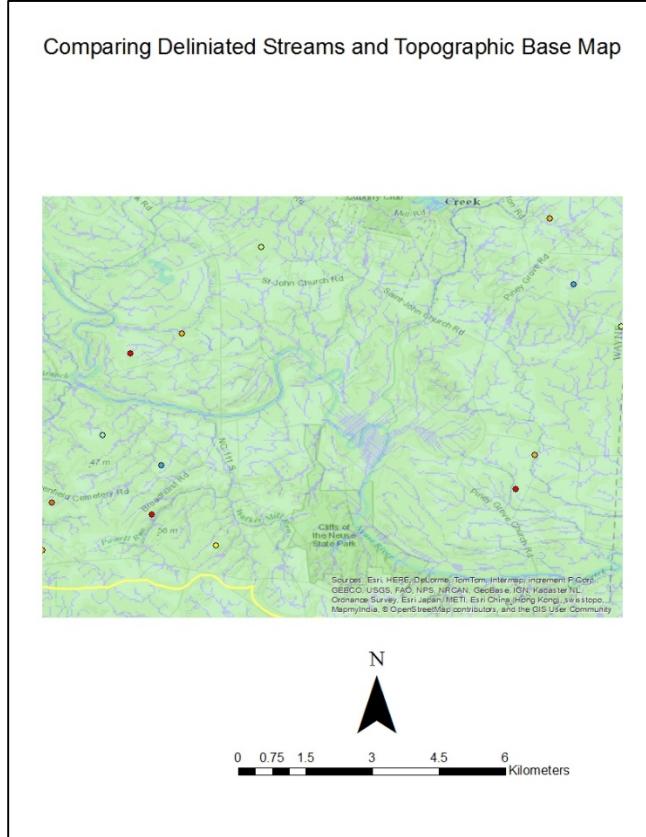
Figure 3

The "D-Infinity Distance Down" was one of the most critical tools in the analysis of these data. The tool takes all of the usual stream information, flow direction, accumulation, etc. and the raster dataset of streams created above and establishes the distance from every point to the nearest stream segment along the stream flow path. This was one of the first steps of the project that allowed for real analysis. Once the distance to streams had been calculated, it could be extracted for each of the points representing a swine operation in the watershed. This tool is a very particular tool and required that every file used in it be a .tif file and be represented on the same projection and over the same geographic extent. However, once that is dealt with, the tool is very easy to utilize. The example data in figure 4 is taken from the same area surrounding the Cliffs of the Neuse State Park.
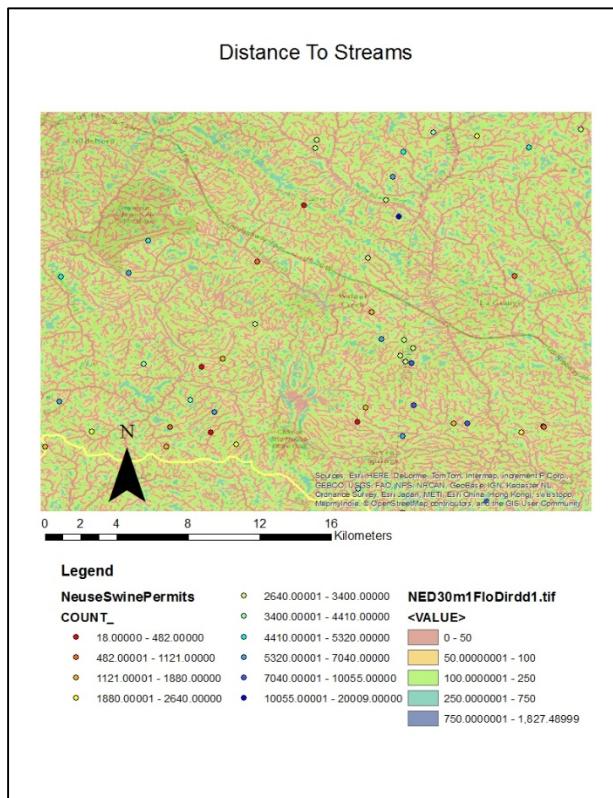
Figure 4

Having a raster of distances to streams, and a class of points representing swine

operations allowed me to collect the zonal statistics at each of the points. The "Zonal Statistics"

tool created a table where each individual permit number was tied from a point to the value of

the distance to stream raster. The table is a bit cumbersome before being edited, but since

each point has only one value, the min, max, mean, and sum are all the same number. That

number is the distance in meters to the nearest stream. The table below is a sample of the first

20 data points in the spreadsheet. There are over 570 total points. The first column is the

unique Permit Number and the Sum column stands in as distance.

| PERMIT_NUM	ZONE_CODE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
AWS070007	351	1	956.17507951300	34.18709945680	34.18709945680	0.00000000000	34.18709945680	0.00000000000	34.18709945680
AWS070011	352	1	956.17507951300	123.68832397500	123.68832397500	0.00000000000	123.68832397500	0.00000000000	123.68832397500
AWS250001	467	1	956.17507951300	103.36111450200	103.36111450200	0.00000000000	103.36111450200	0.00000000000	103.36111450200
AWS250004	353	1	956.17507951300	142.77371215800	142.77371215800	0.00000000000	142.77371215800	0.00000000000	142.77371215800
AWS250006	354	1	956.17507951300	149.30502319300	149.30502319300	0.00000000000	149.30502319300	0.00000000000	149.30502319300
AWS250007	305	1	956.17507951300	130.95295715300	130.95295715300	0.00000000000	130.95295715300	0.00000000000	130.95295715300
AWS250008	355	1	956.17507951300	164.36216735800	164.36216735800	0.00000000000	164.36216735800	0.00000000000	164.36216735800
AWS250009	416	1	956.17507951300	235.54962158200	235.54962158200	0.00000000000	235.54962158200	0.00000000000	235.54962158200
AWS250010	306	1	956.17507951300	254.87957763700	254.87957763700	0.00000000000	254.87957763700	0.00000000000	254.87957763700
AWS250011	356	1	956.17507951300	123.68832397500	123.68832397500	0.00000000000	123.68832397500	0.00000000000	123.68832397500
AWS250013	307	1	956.17507951300	79.76168060300	79.76168060300	0.00000000000	79.76168060300	0.00000000000	79.76168060300
AWS250016	357	1	956.17507951300	30.92208099370	30.92208099370	0.00000000000	30.92208099370	0.00000000000	30.92208099370
AWS250017	358	1	956.17507951300	174.30345153800	174.30345153800	0.00000000000	174.30345153800	0.00000000000	174.30345153800
AWS250019	308	1	956.17507951300	95.55097961430	95.55097961430	0.00000000000	95.55097961430	0.00000000000	95.55097961430
AWS250020	359	1	956.17507951300	169.83872985800	169.83872985800	0.00000000000	169.83872985800	0.00000000000	169.83872985800
AWS250021	468	1	956.17507951300	63.70145416260	63.70145416260	0.00000000000	63.70145416260	0.00000000000	63.70145416260
AWS250022	360	1	956.17507951300	163.82453918500	163.82453918500	0.00000000000	163.82453918500	0.00000000000	163.82453918500
AWS250024	309	1	956.17507951300	85.24867248540	85.24867248540	0.00000000000	85.24867248540	0.00000000000	85.24867248540
AWS250029	361	1	956.17507951300	252.73912048300	252.73912048300	0.00000000000	252.73912048300	0.00000000000	252.73912048300

Table 1

The last factor to work with the animal population, and the distance to nearest stream from operations, is the land cover surrounding the operation. This is important because if the ground is mostly impervious, any runoff from the operation will not be absorbed and a greater percentage of it will be able to reach streams and rivers. This portion utilized the National Land Cover Database and the "Buffer" tool in ArcGIS to set a buffer around the animal operations and determine the average permeability of the ground. The buffer distance was set at 133 meters because that was the average distance between and animal operation and the nearest stream. Obviously, an average is not the best method, but it is a better estimation for a wide array of points. In addition to land cover type, the NCLD contains the % permeability of the ground, and that value will be collected using the same "Zonal Statistics" tool. Table 2 lists the statistics collected for each buffer, and figure 5 shows what the buffers looked like near the Cliffs of the Neuse. The mean column shows the average % permeability of the ground within the buffer. Again, these are the first 20 samples.

PERMIT_NUM	ZONE_CODE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM	VARIETY	MAJORITY	MINORITY	MEDIAN
AWS070007	1	60	54000.000	11	95	84	50.217	39.395	3013.000	4	11	82	11
AWS070011	2	64	57600.000	31	82	51	70.047	21.604	4483.000	2	82	31	82
AWS250001	3	61	54900.000	11	95	84	69.279	28.915	4226.000	6	82	11	82
AWS250004	4	64	57600.000	52	90	38	74.469	14.882	4766.000	3	82	90	82
AWS250006	5	61	54900.000	41	82	41	57.754	18.504	3523.000	5	82	42	43
AWS250007	6	64	57600.000	52	95	43	82.703	10.461	5293.000	3	82	52	82
AWS250008	7	62	55800.000	21	95	74	81.339	22.099	5043.000	4	90	21	90
AWS250009	8	59	53100.000	21	95	74	76.458	18.548	4511.000	5	82	90	82
AWS250010	9	63	56700.000	11	82	71	56.667	28.407	3570.000	6	82	31	71
AWS250011	10	64	57600.000	11	90	79	54.969	34.213	3518.000	6	82	21	82
AWS250013	11	60	54000.000	42	90	48	77.367	14.848	4642.000	4	82	42	82
AWS250016	12	61	54900.000	21	90	69	63.492	27.421	3873.000	5	82	52	82
AWS250017	13	62	55800.000	21	95	74	76.903	18.230	4768.000	5	82	71	82
AWS250019	14	62	55800.000	82	95	13	82.839	3.194	5136.000	2	82	95	82
AWS250020	15	64	57600.000	11	90	79	73.375	21.714	4696.000	4	82	90	82
AWS250021	16	63	56700.000	42	82	40	64.619	19.470	4071.000	4	82	52	82
AWS250022	17	59	53100.000	42	82	40	67.593	16.496	3988.000	3	82	42	82
AWS250024	18	62	55800.000	42	82	40	60.548	15.964	3754.000	5	52	43	52
AWS250029	19	60	54000.000	21	90	69	69.100	23.845	4146.000	6	82	43	82

Table 2

Swine Operation Buffers and Land Cover

Legend

NeuseSwinePermits
COUNT_
- 18.00000 - 482.00000
- 482.00001 - 1121.00000
- 1121.00001 - 1880.00000
- 1880.00001 - 2640.00000
- 2640.00001 - 3400.00000
- 3400.00001 - 4410.00000
- 4410.00001 - 5320.00000
- 5320.00001 - 7040.00000
- 7040.00001 - 10055.00000
- 10055.00001 - 20009.00000

NeusLandUse1.tif
LAND_COVER
- Open Water
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Barren Land
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrub/Scrub
- Herbaceous
- Hay/Pasture
- Cultivated Crops
- Woody Wetlands
- Emergent Herbaceuous Wetlands

Figure 5

Conclusions

Creating the buffer layer was the last step in setting the stage to perform the final analysis. After exporting the attribute tables for the swine operations, the distance to streams, and the average permeability around hog farms, all three were merged into a single Microsoft Excel spreadsheet. Some data had to be worked with a little to have it all fit together correctly, for instance, in a few cases one permit number would identify multiple different operations based on more detailed parameters of what was being done. For example, breeding, slaughter, boars, sows, etc. I chose to leave everything the way it is and not try and consolidate any of that data. Using all three of the parameters I collected, animal count, distance to streams, and permeability of surrounding land I ran the "Rank" function in excel to rank each of the permits

in each category. Then I averaged all three rankings to create a cumulative ranking. All four rankings are available in table 3. The rankings look for operations that are, simply put, small, far away from water, and surrounded by highly permeable surfaces. The table would be useful to any agency, government or non-government looking to identify potential locations for new methods of trying to contain hog waste in North Carolina farming operations. Admittedly, some of the analysis is a bit crude. Using NHD stream data instead of delineating streams would lead to more accurate distances to streams, although is difficult due to the need for it to be in a .tif raster. The ranking system could also be improved if there were a way to weight the different categories for which one poses more danger than the others. Right now the three categories are weighted equally. More research into this topic would be very important; North Carolina is heavily reliant on the pork industry, and that is not going to change. It is very important that the state try and make it as environmentally responsible and sustainable as possible.

Permit Number	Count (Animals)	Count Rank	Distance to Stream (m)	Distance Rank	Mean Permiability (of Buffer)	Permiability Rank	Overall Average Ranking
AWS960177	550	38	211.1492	88	86.234	11	46
AWS960143	752	55	261.5082	42	82.934	73	57
AWS820521	620	48	226.1767	73	83.677	55	59
AWS960177	1400	93	211.1492	88	86.234	11	64
AWS540073	2400	159	349.2613	12	85.250	22	64
AWS960125	1224	85	344.2551	13	82.032	107	68
AWS960103	80	4	260.2127	43	78.557	208	85
AWS960179	600	41	154.0533	193	85.302	21	85
AWS960078	2350	158	343.3574	14	82.567	85	86
AWS540042	2880	207	277.1014	32	85.383	20	86
AWS540139	600	41	195.0941	126	82.241	93	87
AWS960082	2670	199	266.6509	41	85.200	23	88
AWS960186	650	49	149.3050	205	86.966	10	88
AWS520033	2160	148	355.6973	9	82.000	108	88
AWS960151	100	5	133.3472	234	84.983	26	88
AWS540138	2640	193	363.7937	7	83.275	66	89
AWS400027	1000	68	157.8708	186	85.968	17	90
AWS730002	200	17	202.3730	107	81.000	151	92
AWS960203	480	34	266.7853	39	78.754	204	92
AWS960106	1224	85	364.6996	6	79.483	194	95
AWS980017	425	32	148.6879	207	83.726	52	97
AWS960114	1440	98	204.6702	99	82.133	97	98
AWS540068	1440	98	194.4368	129	83.094	70	99
AWS400047	2880	207	270.4979	37	83.290	65	103
AWS540095	525	36	197.3267	120	80.966	153	103
AWS960075	2880	207	274.4372	33	82.738	78	106
AWS540061	1200	80	217.2210	80	80.109	173	111
AWS400068	2169	149	204.5815	100	82.390	89	113
AWS740024	1500	112	324.2267	19	78.557	208	113
AWS510024	3000	243	354.0063	10	82.250	92	115
AWS960120	1200	80	161.1145	180	82.400	88	116
AWS510110	2412	167	203.7251	101	82.213	94	121
AWS520041	2700	201	238.1915	64	82.063	104	123
AWS400093	1400	93	165.9462	171	82.000	108	124
AWS520015	3520	273	245.7868	55	83.950	44	124
AWS960203	2000	135	266.7853	39	78.754	204	126
AWS510032	2880	207	211.1492	88	82.629	84	126
AWS960073	2880	207	182.5149	139	84.603	33	126
AWS510125	1050	74	180.2271	144	80.459	163	127
AWS960126	4180	341	329.3009	15	85.047	25	127
AWS960103	2000	135	260.2127	43	78.557	208	129
AWS960088	4896	375	306.0509	23	87.328	8	135
AWS510033	2480	179	297.2585	25	78.542	211	138
AWS960119	2400	159	386.7921	4	76.311	255	139
AWS540023	1000	68	236.7659	66	74.200	290	141
AWS520004	3174	252	194.6167	127	83.750	49	143
AWS960165	200	17	127.9941	241	80.078	174	144
AWS520039	2680	200	244.5131	56	79.984	178	145
AWS510123	3840	299	210.5591	94	83.983	42	145
AWS540109	2400	159	149.3050	205	83.085	71	145
AWS520070	2000	135	151.7244	195	82.000	108	146
AWS510035	2480	179	161.5491	179	82.639	82	147
AWS400058	2448	170	132.6234	235	84.183	38	148
AWS540051	2640	193	136.4967	226	84.742	31	150
AWS540064	3360	265	218.5410	77	82.000	108	150
AWS400088	2000	135	112.9394	276	84.050	41	151
AWS540111	960	67	68.7381	377	87.246	9	151
AWS960122	1240	88	214.8534	83	74.574	282	151
AWS540087	550	38	254.2451	50	70.085	367	152
AWS960118	1121	77	138.8506	221	80.738	157	152
AWS540037	3520	273	189.2417	134	83.733	51	153
AWS540050	2880	207	371.8699	5	76.750	247	153
AWS400049	2880	207	356.8098	8	76.790	245	153
AWS510038	1750	123	197.6354	118	77.952	223	155
AWS540125	1200	80	74.8607	350	84.167	39	156
AWS250047	1500	112	104.5487	301	83.311	64	159
NCA240041	400	29	117.0896	269	79.781	182	160
AWS400083	1400	93	61.8442	388	91.066	2	161
AWS740116	1760	125	74.6525	352	87.617	7	161
AWS960111	1440	98	131.7521	236	81.032	150	161
AWS730008	175	15	278.9109	31	64.871	439	162
AWS250029	720	52	252.7391	52	69.100	383	162
AWS400037	4896	375	232.6628	68	83.950	44	162
AWS400033	3670	286	226.4156	71	81.710	131	163
AWS510104	2205	154	136.4967	226	82.000	108	163
AWS960206	2400	159	91.0090	323	87.933	6	163
AWS400152	1920	134	122.7381	256	82.129	102	164
AWS400156	2600	186	192.0587	131	80.000	177	165
AWS400069	2169	149	174.2108	158	79.651	188	165
AWS540071	1440	98	211.1492	88	73.281	310	165
AWS400053	2640	193	122.6993	257	83.898	48	166
AWS540049	2240	155	92.7662	316	84.852	27	166
AWS400128	4160	335	279.4257	30	81.531	136	167
AWS730006	1300	92	176.1044	150	76.017	259	167
AWS960178	1200	80	197.5901	119	73.619	302	167
AWS510048	2480	179	105.5746	288	84.459	36	168
AWS960096	320	24	37.9051	427	83.705	53	168
AWS960127	2285	157	93.6368	314	84.516	34	168
AWS540034	3520	273	157.6788	187	83.922	46	169
AWS510046	1600	117	107.7547	283	82.000	108	169
AWS960109	1440	98	74.6525	352	83.467	59	170
AWS400061	1757	124	177.8951	148	77.000	238	170
AWS540120	2975	240	178.1153	147	81.984	126	171
AWS540021	4800	368	201.9245	109	84.344	37	171
AWS400142	3000	243	149.3050	200	82.885	74	172
AWS740075	722	54	113.1452	275	79.651	188	172
AWS400162	3000	243	156.1397	189	82.419	87	173
AWS740047	2840	206	159.8711	181	81.698	132	173
NCA240041	1000	68	117.0896	269	79.781	182	173

AWS960006	1000	68	201.2630	110	71.344	347	175
AWS540070	1440	98	140.1992	216	78.365	215	176
AWS510113	3900	314	211.6128	87	81.783	129	177
AWS520041	4750	366	238.1915	64	82.063	104	178
AWS400080	1480	110	136.4967	226	79.016	200	179
AWS520078	600	41	0.0000	479	85.864	18	179
AWS960089	2448	170	322.3137	20	71.242	350	180
AWS540062	2500	184	242.6887	58	73.714	299	180
AWS510065	543	37	138.4680	222	74.526	283	181
AWS250050	3200	253	105.5746	288	90.033	3	181
AWS960164	350	27	229.1845	70	63.839	449	182
AWS540029	4700	365	436.0239	2	79.836	180	182
AWS400050	3840	299	180.6240	141	82.000	108	183
AWS960171	1411	97	61.8442	388	83.361	63	183
AWS960184	2880	207	198.3409	116	77.533	227	183
AWS400143	4695	363	199.6402	114	82.810	76	184
AWS400038	3672	287	130.7297	239	84.838	28	185
AWS740025	3840	299	143.1432	213	83.969	43	185
AWS960098	160	12	30.9221	446	82.133	97	185
AWS400131	4310	347	159.0879	184	84.774	30	187
AWS960042	3672	287	206.7476	98	80.032	176	187
AWS510045	1760	125	41.3802	422	86.129	15	187
AWS960182	6400	441	202.3702	108	86.016	16	188
AWS740067	1188	79	167.8665	167	72.897	321	189
AWS250009	3144	250	235.5496	67	76.458	251	189
AWS540002	2700	201	189.6129	132	77.067	236	190
AWS510040	160	12	61.8442	388	80.117	171	190
AWS960041	3672	287	186.8972	137	81.148	147	190
AWS510076	280	21	173.1308	161	68.937	390	191
AWS960201	4200	342	164.8519	173	83.492	58	191
AWS400095	1636	120	203.6390	102	71.194	352	191
AWS520007	4000	317	149.3050	200	83.600	57	191
AWS960090	2448	170	139.6392	219	79.678	186	192
AWS540135	4896	375	241.7378	59	81.333	143	192
AWS400121	2600	186	151.3664	197	79.049	198	194
AWS540144	2400	159	274.1942	34	68.983	389	194
AWS510106	5536	410	222.5356	74	82.131	100	195
AWS540043	5760	416	180.2271	142	84.689	32	197
AWS510076	580	40	173.1308	161	68.937	390	197
AWS960135	2448	170	148.3329	208	78.460	213	197
AWS960037	3675	294	200.0758	113	79.742	185	197
AWS960091	2988	241	127.4128	243	82.000	108	197
AWS540008	7200	456	253.3488	51	82.484	86	198
AWS250049	4896	375	247.0615	54	80.246	166	198
AWS520057	616	47	32.7928	441	82.000	108	199
AWS960074	2880	207	212.8743	85	73.492	305	199
AWS740072	1815	130	105.5746	288	79.828	181	200
AWS510007	1240	88	175.3768	152	70.371	361	200
AWS960138	5217	404	479.2589	1	79.188	196	200
AWS250008	3672	287	164.3622	174	81.339	142	201
AWS960137	840	64	35.1345	436	82.000	108	203
AWS510102	4410	359	349.9323	11	76.933	240	203
AWS740108	3840	299	325.3508	17	73.847	296	204
AWS960064	2880	207	175.6352	151	76.180	256	205
AWS960096	2000	135	37.9051	427	83.705	53	205
AWS980027	898	65	104.9701	300	76.525	250	205
AWS960102	1836	132	83.6812	340	81.266	144	205
AWS520026	7200	456	198.3409	116	83.750	49	207
AWS740073	824	61	211.1492	92	60.820	471	208
AWS540036	3520	273	139.9828	217	81.567	135	208
AWS250036	5200	396	270.9790	35	79.413	195	209
AWS640072	600	41	195.4248	124	61.721	462	209
AWS250033	1400	93	182.3120	140	68.667	397	210
AWS400043	4000	317	113.7112	274	84.097	40	210
AWS960093	2448	170	163.4345	177	74.517	284	210
AWS960030	4280	346	136.8842	225	83.415	61	211
AWS250019	3093	249	95.5510	310	82.839	75	211
AWS960035	4320	350	187.4555	136	81.033	149	212
AWS400044	4000	317	327.8958	16	73.517	304	212
AWS520065	2448	170	180.0301	146	72.885	322	213
AWS540080	800	56	150.0834	199	69.033	384	213
AWS400026	4000	317	126.2157	244	82.688	80	214
AWS960062	2880	207	212.0049	86	71.276	349	214
AWS920012	263	19	88.5568	329	73.738	297	215
AWS960005	7350	464	257.5852	45	81.500	137	215
AWS510068	380	28	124.5697	246	69.836	373	216
AWS540014	5040	393	208.9516	95	80.661	159	216
AWS540103	120	9	105.5746	295	71.500	343	216
AWS960121	1240	88	105.6726	286	75.200	274	216
AWS400063	2200	152	165.3334	172	72.689	325	216
AWS960115	1440	98	30.9221	446	82.000	108	217
NCA240040	3000	243	180.2271	144	75.683	265	217
AWS540028	3840	299	256.6553	47	73.356	309	218
AWS400091	720	52	0.0000	479	81.967	127	219
AWS510029	2880	207	95.0730	311	81.344	141	220
AWS400055	2600	186	297.3228	24	63.677	451	220
AWS960214	5200	396	163.7055	176	82.385	90	221
AWS540126	1440	98	175.0842	154	67.475	411	221
AWS250020	2629	192	169.8387	166	73.375	308	222
AWS740021	4896	375	118.3829	262	84.828	29	222
AWS250007	4320	350	130.9530	238	82.703	79	222
AWS960116	1440	98	74.6525	352	78.133	218	223
AWS510041	1291	91	199.2733	115	61.241	467	224
AWS960139	7500	466	173.6372	160	83.902	47	224
AWS960199	4320	350	203.1498	104	78.098	219	224
AWS960112	1440	98	124.0155	248	72.550	328	225
AWS980015	180	16	139.8041	218	64.667	440	225
AWS540099	1880	133	226.3489	72	60.446	473	226
AWS400097	810	59	194.6110	128	51.203	496	228
AWS400120	4310	347	118.1292	267	83.167	69	228

AWS400157	2600	186	106.9325	285	78.500	212	228
AWS740113	3860	312	127.5308	242	81.783	129	228
AWS520024	2880	207	94.4332	313	80.441	164	228
AWS400147	2800	203	71.9339	374	82.000	108	228
AWS400153	9792	492	284.6790	28	80.203	167	229
AWS540141	7040	455	170.3915	165	83.230	67	229
AWS510063	2416	168	38.7162	425	82.148	95	229
AWS520060	3520	273	92.7662	316	82.131	100	230
AWS250022	1480	110	163.8245	175	67.593	406	230
AWS510040	2000	135	61.8442	388	80.117	171	231
AWS510068	1094	75	124.5697	246	69.836	373	231
AWS960157	125	10	30.9221	446	76.935	239	232
AWS250038	2600	186	105.5746	288	77.891	225	233
AWS960040	3672	287	87.5253	330	82.639	82	233
AWS510122	600	41	146.4139	209	63.500	452	234
AWS540033	6000	435	123.6883	249	85.200	23	236
AWS400102	4160	335	324.9677	18	70.873	355	236
AWS510039	2495	183	122.5952	258	75.656	267	236
AWS400094	12000	505	254.3373	49	80.762	156	237
AWS400140	3672	287	134.0276	233	79.610	191	237
AWS730005	18	1	89.3031	325	69.000	386	237
AWS520013	3520	273	131.1285	237	78.767	203	238
AWS730005	20	2	89.3031	325	69.000	386	238
AWS980009	1700	122	118.3829	262	72.523	329	238
AWS540137	7680	469	156.8215	188	83.443	60	239
NCA240041	3400	267	117.0896	269	79.781	182	239
AWS400099	2550	185	89.1052	328	78.651	206	240
AWS960100	125	10	138.4054	223	54.656	488	240
AWS960190	2880	207	144.9529	211	73.393	307	242
AWS250031	5200	396	118.3829	262	83.200	68	242
AWS400016	3840	299	39.5558	423	88.689	5	242
AWS960134	100	5	61.8442	388	71.885	335	243
AWS510103	6480	447	420.0970	3	74.689	281	244
AWS540122	3520	273	159.6353	182	74.721	279	245
AWS510020	3720	295	62.8667	386	83.631	56	246
AWS510028	2880	207	193.6535	130	67.938	401	246
AWS400060	8000	477	189.0317	135	81.867	128	247
AWS510083	100	5	30.9221	446	74.164	291	247
AWS730005	445	33	89.3031	325	69.000	386	248
AWS960044	3672	287	149.3050	200	76.091	258	248
AWS400004	3466	268	308.9547	22	62.847	458	249
AWS510052	1040	73	135.5877	232	64.594	443	249
AWS540032	3600	283	229.9558	69	68.688	396	249
AWS960068	2880	207	79.6217	345	79.143	197	250
AWS540124	4000	317	210.9481	93	71.677	340	250
AWS960021	5600	411	125.2447	245	82.138	96	251
AWS740115	4250	345	238.3714	62	71.279	348	252
AWS960050	3200	253	203.1781	103	67.905	402	253
AWS960072	2880	207	0.0000	479	83.033	72	253
AWS960014	5760	416	87.4609	331	86.233	13	253
AWS510011	5200	396	196.5709	122	76.875	243	254
AWS960004	3790	297	92.7662	316	81.092	148	254
AWS960079	2880	207	180.2271	142	67.383	412	254
AWS540123	3840	299	216.4232	82	69.213	381	254
AWS250011	400	29	123.6883	249	54.969	485	254
AWS540069	1440	98	87.4609	331	71.906	334	254
AWS540002	5200	396	189.6129	132	77.067	236	255
AWS740037	2880	207	80.1336	343	78.328	216	255
AWS540142	3840	299	153.1150	194	75.016	275	256
AWS400163	7200	456	280.2830	29	74.460	286	257
AWS960092	2448	170	105.6245	287	73.129	315	257
AWS250041	3840	299	94.8259	312	80.557	162	258
AWS960060	3200	253	257.5263	46	60.302	474	258
AWS540127	2640	193	61.8442	388	79.533	193	258
AWS070011	2245	156	123.6883	249	70.047	370	258
AWS520070	8000	477	151.7244	195	82.000	108	260
AWS510021	3720	295	92.7662	316	80.121	170	260
AWS640030	3631	285	99.0022	308	79.613	190	261
AWS960012	5760	416	118.3829	262	82.000	108	262
AWS400084	9207	490	294.4074	27	75.500	270	262
AWS400089	1446	109	30.9221	446	77.306	233	263
AWS520042	2400	159	53.9158	410	78.000	220	263
AWS400160	4000	317	87.3272	334	81.429	139	263
AWS730011	40	3	36.8345	430	70.516	358	264
AWS520012	2640	193	119.0247	261	71.563	341	265
AWS540132	4160	335	30.9221	446	86.167	14	265
AWS510009	8044	480	159.5369	183	81.583	133	265
AWS400005	10500	496	267.0738	38	75.734	263	266
AWS540046	2880	207	71.5309	375	78.150	217	266
AWS400144	3840	299	108.6029	281	78.000	220	267
AWS250011	1000	68	123.6883	249	54.969	485	267
AWS540009	8640	486	123.6844	254	83.371	62	267
AWS250010	3520	273	254.8796	48	56.667	482	268
AWS520027	2800	203	30.9221	446	80.794	155	268
AWS740006	11225	499	242.8189	57	76.714	248	268
AWS400092	825	62	74.6525	352	68.900	392	269
AWS730011	269	20	36.8345	430	70.516	358	269
AWS960205	4896	375	206.8423	97	71.879	337	270
AWS400032	8569	484	208.1799	96	77.492	230	270
AWS640065	482	35	105.5746	295	57.083	481	270
AWS400070	2169	149	143.0364	214	63.758	450	271
AWS250013	2960	239	79.7617	344	77.367	232	272
AWS400134	4695	363	105.5746	295	80.667	158	272
AWS520072	1600	117	62.9978	384	73.063	316	272
AWS740022	4800	368	174.6541	155	73.967	294	272
AWS960083	5280	405	101.2449	305	82.000	108	273
AWS400057	4896	375	30.9221	446	92.458	1	274
AWS740095	830	63	74.6525	352	67.581	407	274
AWS960056	3200	253	0.0000	479	82.266	91	274
AWS400018	4923	388	216.8750	81	70.698	357	275

AWS400065	2200	152	52.4804	412	75.729	264	276
AWS960094	2424	169	36.3564	433	77.574	226	276
AWS540057	1224	85	74.6525	352	68.803	393	277
AWS400133	3000	243	158.6634	185	67.650	404	277
AWS520002	4380	358	92.7662	316	80.613	160	278
AWS960144	4823	374	117.6293	268	79.600	192	278
AWS740071	11157	498	200.3413	112	77.525	228	279
AWS980023	2000	135	74.6724	351	70.885	354	280
AWS400025	4756	367	201.1596	111	70.100	366	281
AWS960016	5760	416	241.0689	60	70.063	368	281
AWS400110	1160	78	33.8686	439	72.254	330	282
AWS250006	2448	170	149.3050	200	57.754	478	283
AWS540045	2800	203	61.8442	388	76.145	257	283
AWS510061	660	51	0.0000	479	72.950	319	283
AWS520023	3150	251	36.8609	429	80.148	169	283
AWS960049	3200	253	75.4725	349	76.677	249	284
AWS250021	400	29	63.7015	382	64.619	441	284
AWS400062	2000	135	0.0000	479	76.921	241	285
AWS520075	2880	207	167.4188	169	57.672	479	285
AWS740101	4896	375	317.3047	21	62.279	460	285
AWS960127	12960	509	93.6368	314	84.516	34	286
AWS960100	2080	147	138.4054	223	54.656	488	286
AWS960134	2000	135	61.8442	388	71.885	335	286
AWS510001	100	5	74.6525	352	46.210	502	286
AWS520072	2400	159	62.9978	384	73.063	316	286
AWS960063	2880	207	43.7304	417	77.267	235	286
AWS960098	4000	317	30.9221	446	82.133	97	287
AWS540082	600	41	45.1502	416	67.639	405	287
AWS730011	1100	76	36.8345	430	70.516	358	288
AWS960069	2880	207	61.8442	388	75.559	269	288
AWS510129	3360	265	203.1426	105	52.629	495	288
AWS960070	2880	207	0.0000	479	79.908	179	288
AWS540004	20009	511	167.4188	169	79.672	187	289
AWS960034	320	24	0.0000	479	70.125	364	289
AWS250024	820	60	85.2487	336	60.548	472	289
AWS540065	1650	121	74.6525	352	68.694	395	289
AWS960029	4410	359	270.6897	36	58.778	475	290
AWS960010	5760	416	67.6517	378	82.767	77	290
AWS400145	5000	390	67.0701	379	82.033	106	292
AWS540007	6400	441	120.4283	260	80.066	175	292
AWS400158	5747	415	197.0455	121	71.559	342	293
AWS540052	2640	193	139.1805	220	61.645	465	293
AWS510050	4896	375	136.4967	226	74.813	278	293
AWS510005	2012	146	48.3621	414	72.902	320	293
AWS510036	3900	314	102.3507	304	75.754	262	293
AWS740035	3800	298	174.4419	156	66.109	427	294
AWS960065	2880	207	118.3829	262	67.274	413	294
AWS960200	2880	207	111.6193	278	68.452	399	295
AWS540078	650	49	31.0306	444	68.783	394	296
AWS250017	9900	493	174.3035	157	76.903	242	297
AWS960185	4800	368	294.5797	26	46.531	501	298
AWS250004	5200	396	142.7737	215	74.469	285	299
AWS960009	5760	416	217.9922	78	67.889	403	299
AWS740105	5760	416	203.0674	106	69.460	376	299
AWS510030	2880	207	75.6461	348	71.355	345	300
AWS740066	8000	477	154.6104	191	77.295	234	301
AWS400029	4000	317	0.0000	479	82.000	108	301
AWS400024	4000	317	69.5021	376	78.450	214	302
AWS540093	300	23	30.9221	446	64.968	438	302
AWS510007	5100	395	175.3768	152	70.371	361	303
AWS400015	6480	447	183.2981	138	72.700	324	303
AWS540063	1760	125	30.9221	446	71.875	338	303
AWS250048	3840	299	74.6525	352	76.000	260	304
AWS960162	290	22	58.1119	407	56.344	483	304
AWS400030	6720	452	30.9221	446	85.847	19	306
AWS400046	4510	361	43.7304	417	81.422	140	306
AWS960210	3200	253	71.9999	373	74.067	292	306
AWS520077	1800	128	0.0000	479	73.159	312	306
AWS510022	3200	253	31.8069	442	77.450	231	309
AWS540107	800	56	43.7304	417	63.286	454	309
AWS520074	1832	131	105.5746	288	40.917	509	309
AWS640072	4200	342	195.4248	124	61.721	462	309
AWS510107	2940	237	61.8442	388	73.450	306	310
AWS400151	7200	456	250.4744	53	66.222	424	311
AWS520032	2448	170	61.8442	388	69.424	377	312
AWS740014	8400	483	170.5809	164	74.271	289	312
AWS540053	7577	468	238.2574	63	67.508	410	314
AWS520006	4896	375	47.6367	415	80.969	152	314
AWS960057	3200	253	73.9178	371	72.968	318	314
AWS250051	2993	242	154.6104	191	33.738	511	315
AWS400052	2600	186	105.5746	288	60.918	470	315
AWS070007	160	12	34.1871	437	50.217	497	315
AWS510074	334	26	0.0000	479	64.617	442	316
AWS520021	12800	508	84.1241	338	82.125	103	316
AWS740023	4800	368	150.9217	198	69.031	385	317
AWS960031	11520	501	92.7662	316	81.578	134	317
AWS960077	2880	207	61.8442	388	70.793	356	317
NCA252073	3520	273	74.6525	352	72.650	326	317
AWS520064	7680	469	0.0000	479	90.000	4	317
AWS400020	4896	375	149.3050	200	69.339	379	318
AWS520030	5280	405	136.4967	226	72.850	323	318
AWS960136	930	66	30.9542	445	64.590	444	318
AWS960085	2480	179	30.9221	446	72.194	331	319
AWS250016	809	58	30.9221	446	63.492	453	319
AWS960141	1200	80	30.9221	446	65.443	432	319
AWS960192	3500	270	35.4683	435	76.317	254	320
AWS400042	2925	236	101.0221	306	66.565	420	321
AWS510015	4350	357	87.0121	335	75.475	271	321
AWS960007	6120	438	30.9221	446	82.645	81	322
AWS400126	4160	335	61.8442	388	76.813	244	322

AWS400148	6960	453	154.6883	190	72.644	327	323
AWS540058	3624	284	0.0000	479	78.600	207	323
AWS400009	7500	466	122.2459	259	76.778	246	324
AWS520002	10320	495	92.7662	316	80.613	160	324
AWS960161	5210	403	105.5746	288	74.714	280	324
AWS540128	7200	456	214.6119	84	65.359	433	324
AWS740081	8299	482	89.9862	324	80.175	168	325
AWS960055	3200	253	102.9489	303	66.597	419	325
AWS400013	5900	434	222.5041	75	61.000	468	326
AWS400031	3840	299	43.7304	417	75.967	261	326
AWS520018	6400	441	217.4765	79	62.905	457	326
AWS400066	3500	270	83.6811	341	70.062	369	327
AWS510001	1800	128	74.6525	352	46.210	502	327
AWS960058	6400	441	145.2538	210	71.922	333	328
AWS960020	5600	411	74.6525	352	77.951	224	329
AWS400012	6000	435	30.9221	446	82.000	108	330
AWS400042	3280	264	101.0221	306	66.565	420	330
AWS400075	1500	112	0.0000	479	68.435	400	330
AWS520071	5600	411	31.2857	443	81.500	137	330
AWS960008	5880	432	117.0238	272	74.292	288	331
AWS250001	3926	316	103.3611	302	69.279	380	333
AWS540016	7344	461	115.7138	273	75.672	266	333
AWS250011	3500	270	123.6883	249	54.969	485	335
AWS400076	1500	112	30.9221	446	64.500	446	335
AWS960046	7000	454	74.6525	352	79.016	199	335
AWS400039	1600	117	30.9221	446	64.516	445	336
AWS400077	1500	112	0.0000	479	66.117	425	339
AWS510004	2000	135	30.9221	446	65.220	435	339
AWS400161	4310	347	87.4609	331	71.729	339	339
AWS400028	4000	317	136.4967	226	58.729	476	340
AWS740109	4800	368	167.5622	168	56.016	484	340
AWS520005	7450	465	109.2937	280	74.983	277	341
AWS400150	8621	485	240.5614	61	57.951	477	341
AWS520036	2000	135	0.0000	479	67.078	414	343
AWS960197	11520	501	63.0894	383	81.258	145	343
AWS960193	5880	432	35.8757	434	80.359	165	344
AWS960194	4320	350	107.3144	284	68.594	398	344
AWS540006	9600	491	61.8442	388	80.850	154	344
AWS540031	7344	461	173.9273	159	66.968	416	345
AWS400017	5000	390	112.3317	277	69.951	371	346
AWS510111	8700	487	196.1239	123	65.914	429	346
AWS960033	4160	335	58.5519	406	73.717	298	346
AWS520011	8832	488	30.9221	446	82.000	108	347
AWS540018	4960	389	66.9259	380	75.349	273	347
AWS960002	4800	368	105.5746	295	69.113	382	348
AWS680003	4000	317	0.0000	479	76.410	252	349
AWS510108	5760	416	144.2213	212	66.500	422	350
AWS540038	3480	269	0.0000	479	73.619	302	350
AWS520009	7680	469	219.2710	76	42.841	507	351
AWS540017	7344	461	172.7284	163	65.968	428	351
AWS980041	3248	263	72.8436	372	66.790	417	351
AWS250039	2400	159	59.8174	405	53.969	490	351
AWS540130	6500	451	177.6216	149	63.094	455	352
AWS820625	4600	362	30.9221	446	76.328	253	354
AWS960052	6400	441	0.0000	479	81.230	146	355
AWS400045	3000	243	0.0000	479	70.937	353	358
AWS400010	4000	317	108.5701	282	57.386	480	360
AWS960071	2880	207	30.9221	446	66.113	426	360
AWS400051	5280	405	30.9221	446	77.508	229	360
AWS400023	4200	342	30.9221	446	74.034	293	360
AWS510025	2940	237	82.6424	342	46.194	506	362
AWS960183	4160	335	61.8442	388	70.279	363	362
AWS960018	5760	416	59.9499	404	75.587	268	363
AWS540025	5700	414	0.0000	479	78.932	201	365
AWS960215	4000	317	96.4674	309	61.000	468	365
AWS960207	4340	356	30.9221	446	73.855	295	366
AWS520042	7854	474	53.9158	410	78.000	220	368
AWS540005	6480	447	66.1472	381	74.359	287	372
AWS960017	5760	416	122.9067	255	64.250	448	373
AWS960187	4320	350	76.1047	346	66.279	423	373
AWS400014	5760	416	32.8983	440	75.000	276	377
AWS510018	4000	317	74.6525	352	61.707	464	378
AWS740114	3860	312	0.0000	479	71.406	344	378
AWS510112	6080	437	129.4036	240	62.683	459	379
AWS960024	4896	375	61.8442	388	69.462	375	379
AWS400146	4000	317	55.8656	409	67.050	415	380
AWS960051	3200	253	0.0000	479	67.574	409	380
AWS510043	3552	282	38.5840	426	65.328	434	381
NCA240136	8200	481	162.1134	178	52.951	493	384
AWS520034	6338	440	50.4360	413	73.656	300	384
AWS960034	4000	317	0.0000	479	70.125	364	387
AWS400007	9000	489	0.0000	479	78.859	202	390
AWS520014	5280	405	62.3177	387	69.406	378	390
AWS250042	7680	469	74.6525	352	71.230	351	391
AWS400011	10055	494	56.9330	408	75.387	272	391
AWS400019	4896	375	83.9729	339	61.871	461	392
AWS960025	12240	507	105.2222	299	69.949	372	393
AWS520077	5200	396	0.0000	479	73.159	312	396
AWS740095	5830	431	74.6525	352	67.581	407	397
AWS510034	5320	409	0.0000	479	73.262	311	400
AWS510004	4108	334	30.9221	446	65.220	435	405
AWS540003	11300	500	43.7304	417	73.651	301	406
AWS960019	5760	416	0.0000	479	72.100	332	409
AWS510001	5040	393	74.6525	352	46.210	502	416
AWS070007	4000	317	34.1871	437	50.217	497	417
AWS960013	5760	416	75.6955	347	53.017	492	418
AWS520063	10560	497	74.6525	352	66.619	418	422
AWS400141	7680	469	84.1431	337	61.254	466	424
AWS740013	12050	506	110.8226	279	53.806	491	425
AWS400154	3840	299	0.0000	479	48.952	500	426

AWS400022	4320	350	30.9221	446	52.683	494	430
AWS960198	7920	475	0.0000	479	71.350	346	433
AWS510001	6480	447	74.6525	352	46.210	502	434
AWS520077	13123	510	0.0000	479	73.159	312	434
AWS520017	6400	441	30.9221	446	65.594	430	439
AWS510004	6120	438	30.9221	446	65.220	435	440
AWS960204	5760	416	0.0000	479	65.587	431	442
AWS400056	5025	392	30.9221	446	37.220	510	449
AWS960211	5760	416	0.0000	479	63.067	456	450
AWS520001	11933	504	30.9221	446	64.459	447	466
AWS520008	7927	476	38.8065	424	50.078	499	466
AWS960213	11520	501	30.9221	446	42.603	508	485

Table 3

Works Cited and Acknowledgements

Paerl, Hans. *Assessing and managing nutrient-enhanced eutrophication in estuarine and coastal waters: Interactive effects of human and climatic perturbations*. 30 September, 2003.

http://www.nconemap.com/ -- NC OneMap

http://www.mrlc.gov/ -- National Land Cover Database

http://ned.usgs.gov/ -- National Elevation Dataset

http://census.gov – US Census