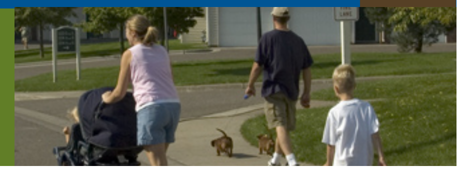
A case study comparison of costs, water quality and quantity benefits, and quality of life.

MINNESOTA LOW IMPACT DEVELOPMENT A COMPARISON

STORMWATER PERFORMANCE



Approach

A goal of the Low Impact Development (LID) design was treatment of every drop of runoff through at least one Best Management Practice (BMP) feature. Stormwater facilities of the LID design included shared space bio-retention areas (with and without under-drains), parking lot bio-retention cells, vegetated swales, roadside rain-gardens, and wet-detention ponds. Modeling of these features guided sizing and provided proof of functionality. By providing at-the-source mitigation of runoff quantity and quality, downstream infrastructure needs were minimized.

Drainage from the site discharges to a tributary of the Vermillion River, a designated trout stream. Within the National Pollutant Elimination Systems (NPDES) and State Disposal Systems (SDS) combined permits, trout streams are classified as a "Special Waters". NPDES "special waters" designation and permit standards are not required for *tributary* drainage (unless the project lies within the same section as the special waters). Therefore, even though the project site is located on a trout stream tributary, "special waters" classification does not apply. However, extra effort was made to meet these more stringent stormwater standards for the LID scenario.

A conscious effort was made to provide extra protection for the Vermillion River during site planning and treatment sizing process though:

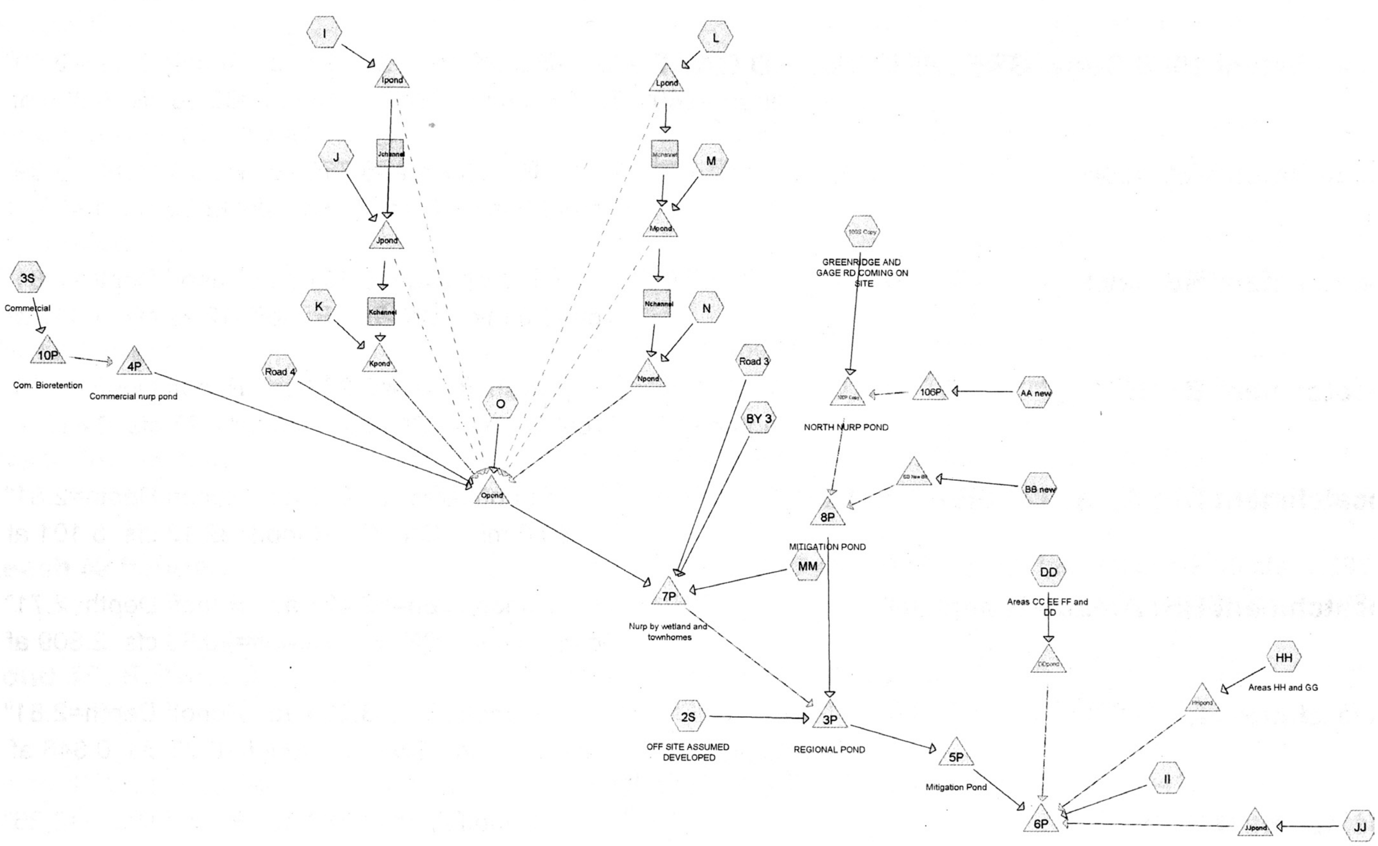
- reduced impervious surfaces
- enhanced pollutant removal
- minimization and control of stormwater discharge
- thermal protection.

Additional detail regarding the federal NPDES/SDS permit program, administered by the Minnesota Pollution Control Agency (MPCA), is available on the MPCA Stormwater Program webpage at: http://www.pca.state.mn.us/water/stormwater/index.html.

Modeling

Model results are presented for a continuum of development scenarios ranging from a conventional design, to the built design, to a low impact development (LID) design. Major stormwater features of the three development scenarios are as follows.

- Conventional – no infiltration, all quantity and quality control through wet detention ponding.
- Built – evolved conventional design with quantity and quality control through wet detention ponding and a regional infiltration basin.
- LID – treatment train approach for increased stormwater cleansing, retention, and groundwater recharge. Maximized, at source, infiltration through bio-retention (including rain gardens, court yard cells, and depressed parking lot islands), overland vegetated conveyance swales, wet detention ponding for additional water quality polishing and rate control, and inclusion of the existing regional infiltration basin for additional volume control (above and beyond site water quality and quantity requirements).



Modeling

HydroCAD (version 7.10) hydrologic/hydraulic modeling software was chosen for project modeling specifically to maintain consistency with that performed (and received) for the “built development” results. Efforts were made to maintain consistency among model parameters for a fair comparison among development scenarios. Model CN’s, site infiltration rates, simulated rainfall events, and pond and reach routing was consistent among the scenarios.

Modeling for the “built” scenario was unaltered from that performed and delivered from the actual site developers with the exception of adding the emergency overflows from the final three basins; the regional pond, mitigation, and infiltration basin.

Modeling of the “conventional” design was similar to that of the “built” design with removal of any infiltration. The regional infiltration basin was converted to a typical wet-detention pond through removal of any exfiltration and changing the starting water level to the normal water level (NWL) as dictated by the outlet invert. Removal of storage and infiltration provided by the regional infiltration basin resulted in an increased need for stormwater peak rate control. Mitigation of peak rates was accomplished by increasing pond surface and available storage to contain storm bounce and limit discharge to the dictated 9 cfs at the southern outlet point. Ponding increases were balanced with adjacent developable area. No changes were made to subwatersheds or stormwater features draining to the northern site outlet.

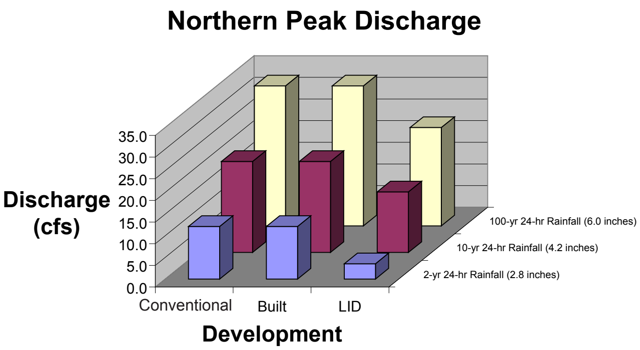
Modeling of the LID design differed from the “conventional” and “built” designs in site layout and stormwater treatment, but maintained consistence in assignment of landuse curve number, site soil properties, and regional infiltration rates.

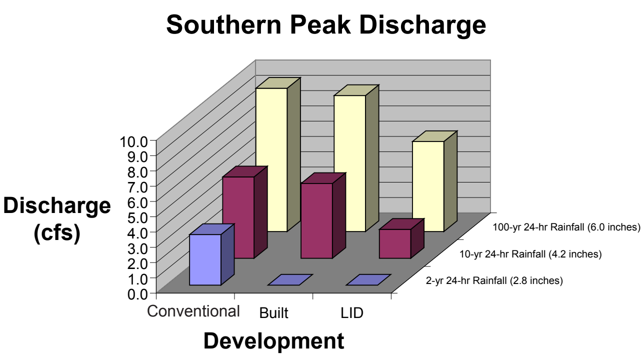
Storm events simulated included design events and longer, complete season simulations. Design events were useful to meet typical standards (i.e 100-year overflow) and show stormwater results necessary to meet permit requirements. Seasonal simulations were most useful to demonstrate realistic pond and basin performance.

Events modeled included:
- 2-year 24-hour rainfall (2.8 inches)
- 10-year 24-hour rainfall (4.2 inches)
- 100-year 24-hour rainfall (6.0 inches)
- Dry Year (20.0 inches)
- Normal Year (26.6 inches)
- Wet Year (35.9 inches)

Stormwater modeling performed to simulate the continuum of development types demonstrated water quality and quantity performance. The results ranged from meeting the bare minimum of permit requirements to going above and beyond site requirements while simultaneously increasing development yield.

Water Quantity





Water Quantity

Stormwater rates and volumes were predicted for the three development scenarios (conventional, built and LID) using a range of single design events and also a “dry”, “normal”, and “wet” year. Peak site discharge results are summarized in Table 1 and Graphs 1 - 2. Total site runoff volume generated along with the portion discharged to the Vermillion River Tributary and the portion infiltrated are tabulated and illustrated in Tables 2-5 and Graphs 3-6.

As visible in the tables and graphs, stormwater peaks and volume discharged from the site tend to decrease moving toward the LID scenario on the development continuum. It can also be observed that total infiltration and groundwater recharge increases moving toward the LID design alternative.

Water Quantity

Table 1 - Peak Discharge (cfs)

Event	Northern Outlet			Southern Outlet		
	Conventional	Built	LID	Conventional	Built	LID
2-yr 24-hr Rainfall (2.8 inches)	12.2	12.2	3.5	3.3	0.0	0.0
10-yr 24-hr Rainfall (4.2 inches)	21.0	21.0	14.0	5.3	4.9	1.9
100-yr 24-hr Rainfall (6.0 inches)	32.3	32.3	22.7	9.4	8.9	5.9
Dry Year (20.0 inches)	23.3	23.3	17.8	5.6	6.2	1.9
Normal Year (26.6 inches)	21.9	21.9	20.4	6.6	9.6	4.9
Wet Year (35.9 inches)	26.0	26.0	25.2	11.7	20.9	6.0

Table 2: Stormwater Runoff Volume during a Normal Year (26.6 inches)

	Conventional	Built	LID
Infiltrated	0	222	511
Discharged	679	455	230
Runoff Generated	679	677	740

Table 3: Stormwater Runoff Volume during a 2 Year 24 hr Event (2.8 inches)

	Conventional	Built	LID
Infiltrated	0	19	28
Discharged	27	7	5
Runoff Generated	27	26	33

Water Quantity

Table 4: Stormwater Runoff Volume during a 10 Year 24 hr Event (4.2 inches)

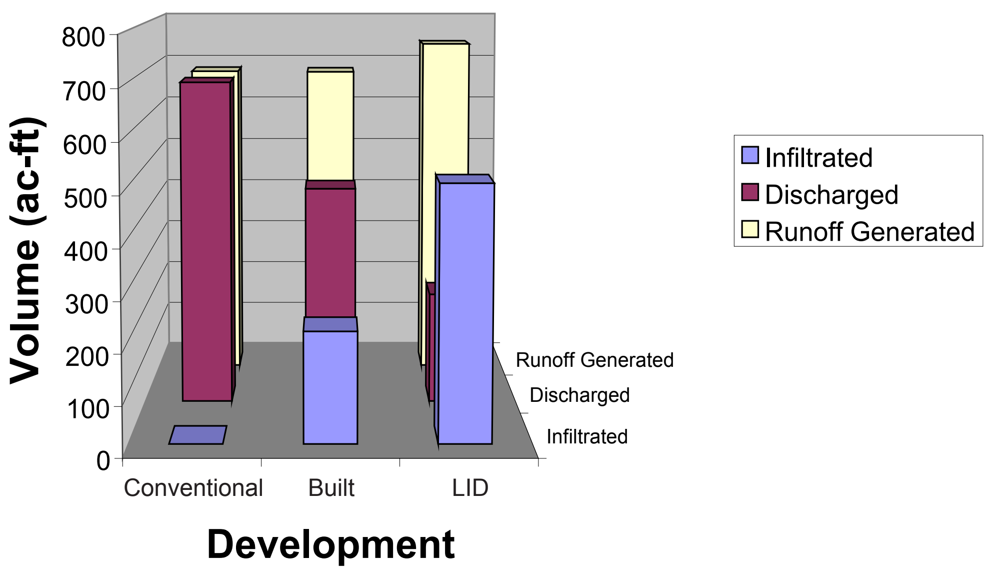
	Conventional	Built	LID
Infiltrated	0	23	42
Discharged	57	33	20
Runoff Generated	57	55	62

Table 5: Stormwater Runoff Volume during a 100 Year 24 hr Event (6.0 inches)

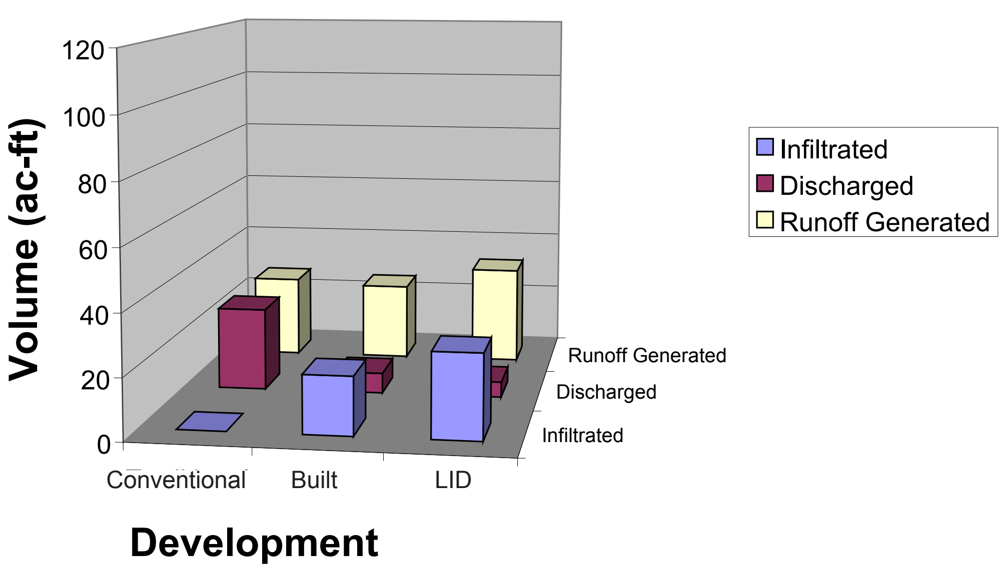
	Conventional	Built	LID
Infiltrated	0	24	50
Discharged	101	75	58
Runoff Generated	101	99	109

Water Quantity

Stormwater Volume during a Normal Year (26.6 inches)

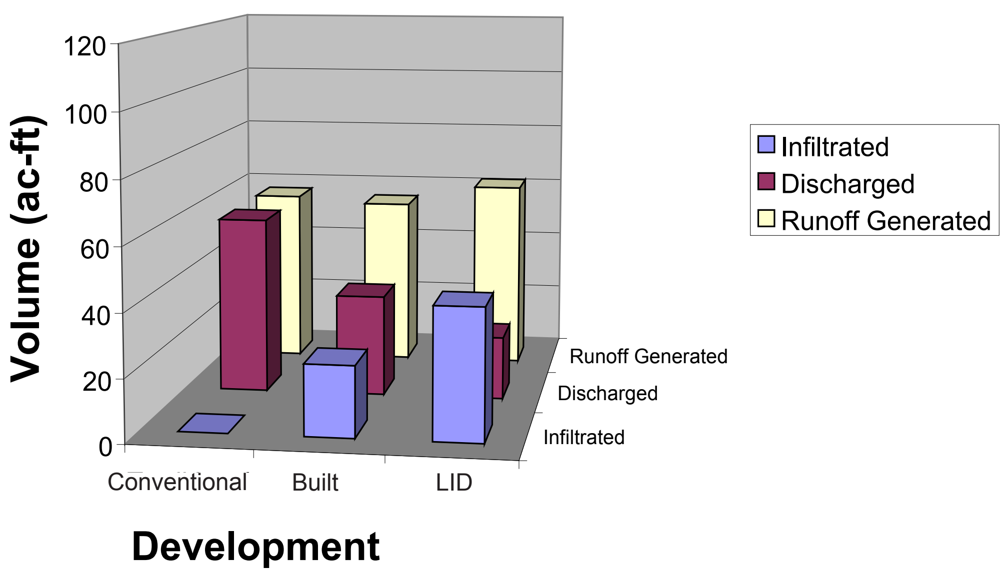


Stormwater Volume during a 2 Year 24 Hour Event (2.8 inches)



Water Quantity

Stormwater Volume during a 10 Year 24 Hour Event (4.2 inches)



Stormwater Volume during a 100 Year 24 Hour Event (6.0 inches)

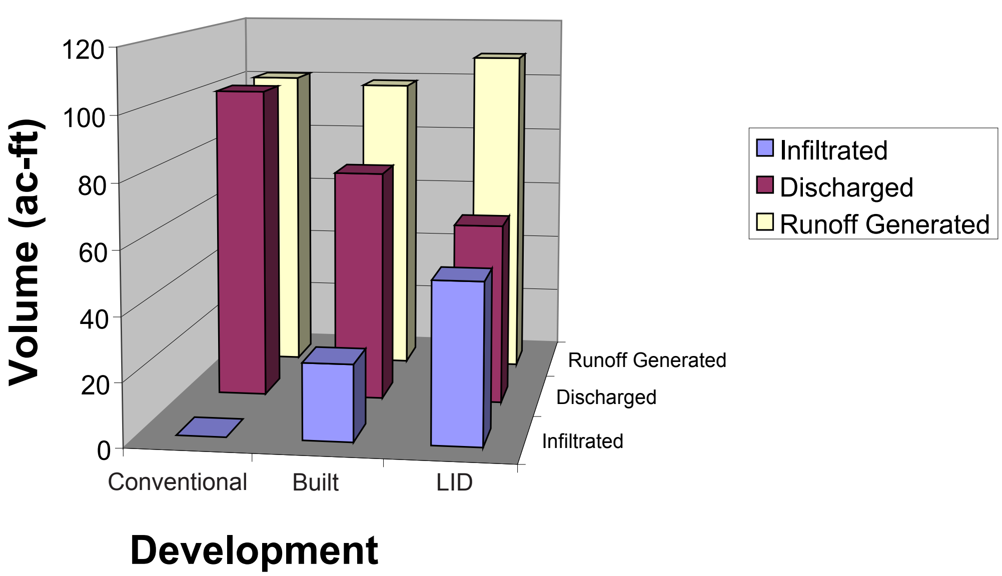


Table 6: Phosphorus Loading

Land Use	P Concentration (ppb)
Open/Predevelopment conditions	50-200
Parks & Public Land	200-300
Rural & Estate Residential	300-400
Low Density Residential	425-475
Medium Density Residential	450-500
High Density Residential	450-500
Commercial/Industrial	475-600
Ponds & Open Water	30-50

Table 7: Median TP removal (%) Mitigative Features

Mitigative Feature	TP % Removal
Infiltration	100
Bio-retention	65
Vegetated Swale	29
Wet-detention/NURP Ponds	60

Water Quality

Water quality features of the three development scenarios consisted of wet detention ponds (NURP ponds), infiltration basins, bio-retention (courtyard cells, rain gardens, depressed parking lot islands), and vegetated swales.

Conventional development water quality features consist solely of wet-detention ponding. The built development water quality is the result of numerous wet-detention ponds and one regional infiltration basin located at the southern site outlet. The water quality of the LID development scenario is the result of bio-retention practices located in the upper portions of the watershed, wet-detention ponding located downstream of bio-retention features, and one regional infiltration basin located at the southern site outlet, as in the build design.

Significant differences between the conventional and built designs with that of the LID design is the location of water quality treatment features. In the conventional and built designs, treatment features are located at low points in the watershed, concentrating treatment at the site outlets. The LID design emphasizes placement of treatment features in the upper portion of the watershed. By doing so and keeping treatment close to the source, treatment efficiency is maximized by allowing for placement in better soils which are more conducive to infiltration and, space is provided to apply a treatment train approach (furthering water quality polishing). Another benefit of placing treatment facilities high in the watershed is protection and increased longevity of downstream facilities. For example, adequate pre-treatment and sediment removal in the upper watershed serves to minimize clogging and maintain infiltration in the downstream regional infiltration basin. This, in turn, minimizes maintenance needs.

Water quality ponding in the features in the conventional and built designs were similar with the exception of the regional infiltration basin. Sizing of LID design stormwater features met and exceeded sizing guidance to satisfy special waters (trout stream) NPDES permit requirements presented in the 2005 MPCA BMP manual.

Water Quality

Water quality, presented as measured by phosphorus loads in pounds per year, were estimated for the three development scenarios based on volume accounting (presented under water quantity results) and treatment feature removal ability. Site generation of phosphorus loads was the result of development landuse. Table 6 presents the phosphorus loading (as a concentration) in ppb for different landuses. Table 7 lists mean total phosphorus removal rates of different treatment features.

To present water quality differences among the development approaches, a simple total phosphorus computation was performed using discharged and infiltrated stormwater volumes generated during a “normal” year. Total phosphorus loads were estimated as a weighted average of the sites removal ability (based on median treatment removal) multiplied by the “normal” years discharged volume. Total and relative phosphorus removal and loading from the three development scenarios are presented in Table 8 – 10 and Graphs 7 - 8.

Table 8: Weighted Development Phosphorus Removal*

	Conventional	Built	LID
Phosphorus Removal (%)	59.4	72.5	90.4

* Assumed Ponds operate at 60% removal, Bio-retention at 65% removal, Infiltrated volume at 100% removal

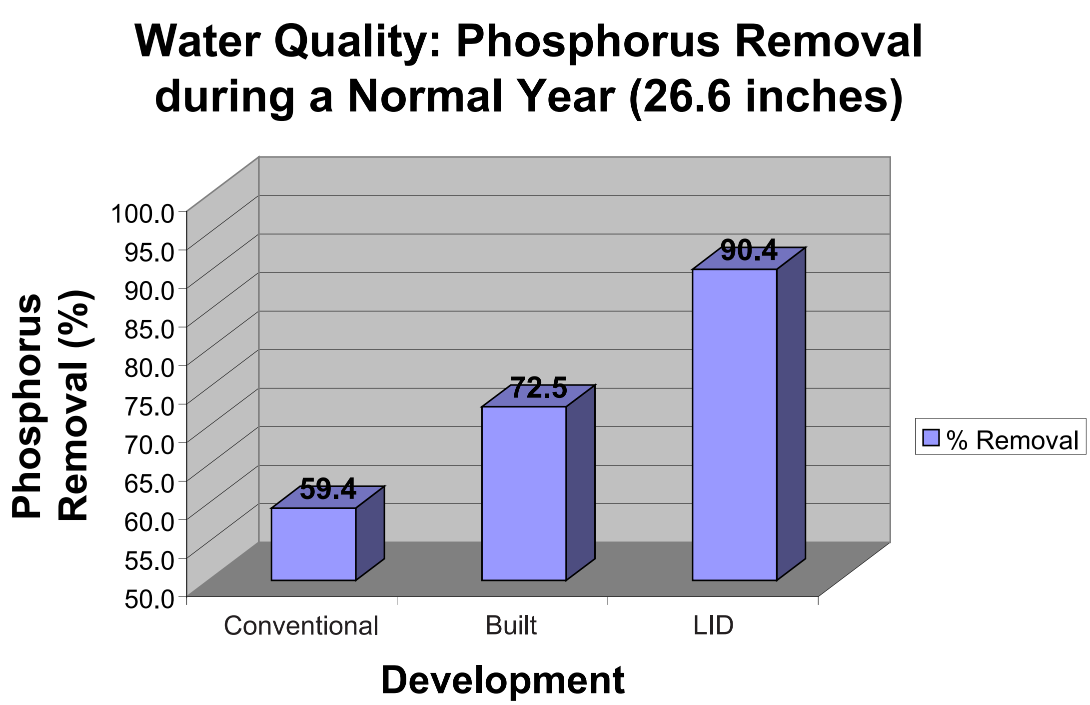
Table 9: Simple Estimation of Annual Phosphorus Discharge Load

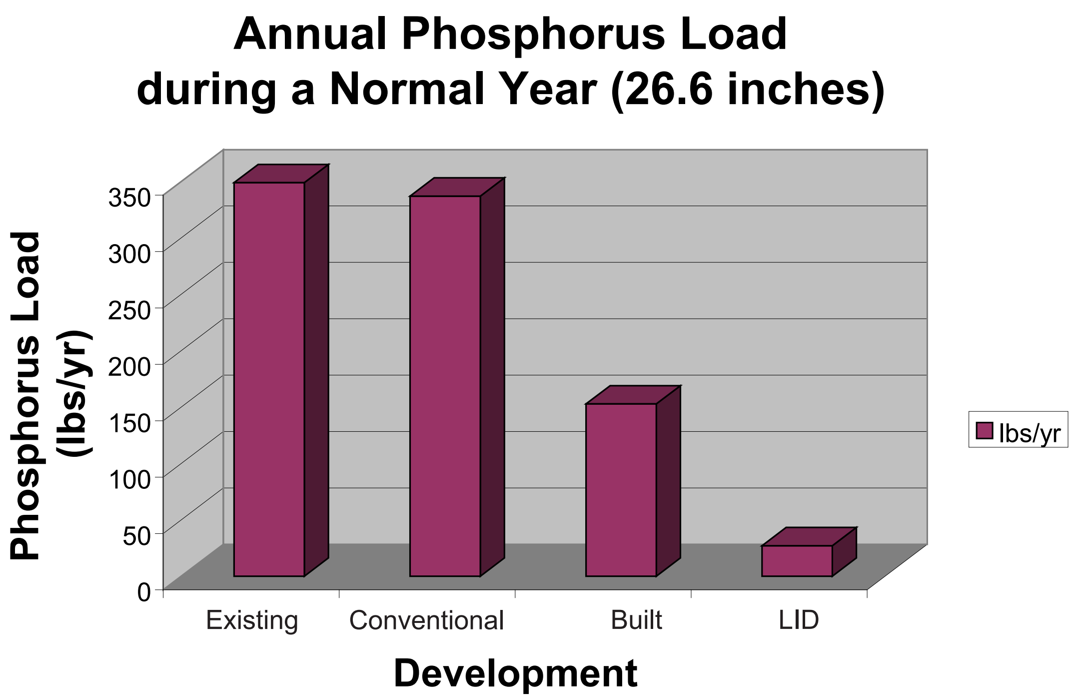
Annual Phosphorus Discharge Load (lbs/yr)	Existing	Conventional	Built	LID
Normal Year, 26.60 inches (lbs/yr)	349	337	153	27

Weighted average P runoff concentration of 300 ppb (existing) and 450 ppb (developed).

Table 10: Relative Phosphorus Load Reduction

Percent Phosphorus Load Reduction over Conventional Design ($lbs-lbs_{trad.}/lbs_{trad.}$)	Conventional	Built	LID
Normal Year (26.60 inches)	-	56	92




Annual Phosphorus Load
during a Normal Year (26.6 inches)
Phosphorus Load (lbs/yr)
350
300
250
200
150
100
50
0
Existing
Conventional
Built
LID
Development
lbs/yr

Stormwater Discussion

Stormwater Discussion

It can be noted that water quantity and quality standards under the LID design were not only met, but dramatically exceeded (and while increasing developable land). This was an intentional outcome of the design comparison. It was not the goal to simply illustrate the additional housing units that could have been added while meeting the bare minimum of stormwater standards. Had this been done, densities could have been further increased. Alternatively, this design was set up to demonstrate a balance between providing exceptional stormwater treatment and increasing site development densities.

Also important to note are the built-in conservative design and treatment elements of the LID scenario. Many LID techniques (such as street narrowing) and alternative stormwater treatment options (such as green roofs, rain barrels, and porous pavement) were *not* employed. This too was also an intentional decision. Although results of the LID scenario would have seen further improvement, it was the team's intention to stick to the more commonly accepted techniques and treatment features that currently appeal to a greater audience.

Lastly, conservative assumptions and back up features were incorporated to address the most skeptical audience. Although all stormwater runoff from the commercial and high density district is treated though depressed island bio-retention facilities, with an under drain, this stormwater receives *unnecessary* secondary treatment through a large wet-detention pond. In the event treatment facilities failed at the first tier defense (parking lot bio-retention), the second tier defense (wet-detention ponding) is sized to handle all NPDES treatment requirements from its contributing area. Similarly, the regional infiltration basin at the end of the system provides a stormwater bonus above and beyond permit requirements. In the event that the regional infiltration basin was to clog, the outlet and basin configuration is such that the site rate controls would be met. So too would the water quality requirements, since all requirements are satisfied prior to this feature. Also interesting to note, because of the extensive pre-treatment provided, it is most likely that the regional infiltration basin of the LID scenario would perform better, for longer, than the same regional infiltration basin as existing in the built development.

Rules/ Regulations Analysis

Rule/Regulation Analysis

New and existing examples of stringent stormwater development standards were used to test the continuum of development scenarios. Permit rules reviewed included:

- NPDES/SDS Construction Permit
- Rice Creek Watershed District (Rule M)
- Wisconsin's River Falls Storm Water Management Ordinance
- NPDES/SDS Municipal Stormwater (MS4) Permit - Nondegradation clause
- Vermillion River Watershed Joint Powers Organization (VRWJPO) Draft Standards (revised 4/12/2006)

Site development under LID design principals was sufficient to meet and exceed the strict stormwater standards reviewed. The built design met some, but not others. The conventional design met rate control standards but failed on volume controls.

NPDES/SDS Construction Permit

The LID design was sized to meet and exceed the MPCA NPDES standards. The water quality volume required at this site was equal to 0.5 inches off new impervious surfaces. However, because this site was on a tributary of a trout stream, the more stringent water quality standard for Special Waters was used as sizing criteria.

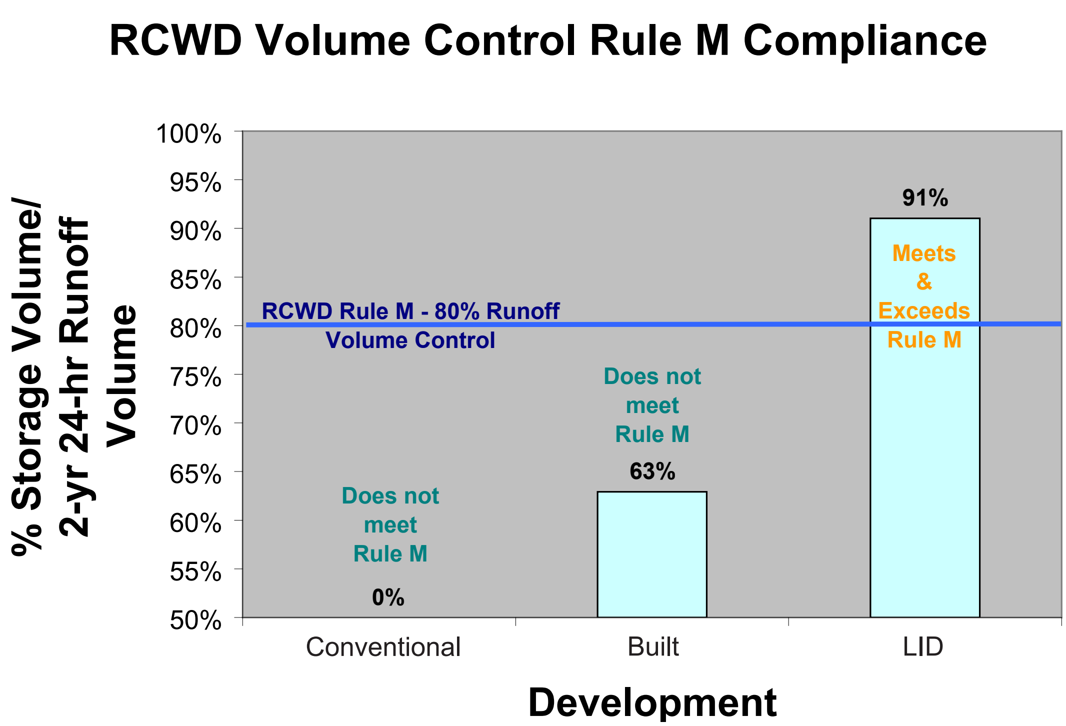
The water quality volume required for Special Waters equals 1.0 inches off new imperious surfaces. Although the site did not technically fall into the Special Waters category, it was treated as such to demonstrate the LID design application on a site with strict development limitations.

The built and conventional designs also met portions of the NPDES Phase II standards. Although Phase II standards did not apply at the time of site development, water quality treatment was satisfied through the wet detention ponding provided. However, it should be noted that the built and conventional designs represent a somewhat unusual case. Additional ponding was necessary at this site to meet extreme peak rate discharge restrictions (a local plan requirement) and extra water quality treatment was a bonus benefit. It is atypical for a development site to exceed requirements at the expense of developable land. In this case, additional ponding and active storage necessary to meet rate controls provided the side benefit of improved water quality.

RCWD Rule M

Rice Creek Watershed District (RCWD) Rule M – Volume Control

According to RCWD's Rule M, a volume equal to the 2-yr 24-hr runoff volume shall be provided with BMPs to retain runoff. Of that total volume, on A/B soils, 20% pre-treatment (flow through) is allowed. Therefore, a minimum of 80% of the runoff generated from a 2-yr 24-hr rainfall event (2.8 inches) must be infiltrated (provided the remaining 20% is accounted for in pre-treatment). In this exercise, the LID development design provides total retention volume equal to 91% of the total site runoff from the 2-yr 24-hr event. The Built design provides a total storage retention volume equal to 63% of the runoff volume within the regional infiltration basin. The Conventional design did not provide volume control. All development scenarios provided up to and in excess of the 20% pre-treatment allowance. The percent BMP storage volume over the total site runoff volume generated from the 2-yr 24-hr design event, for each development scenario, is shown in Graph 9. Calculations exclude flow through runoff from off site.

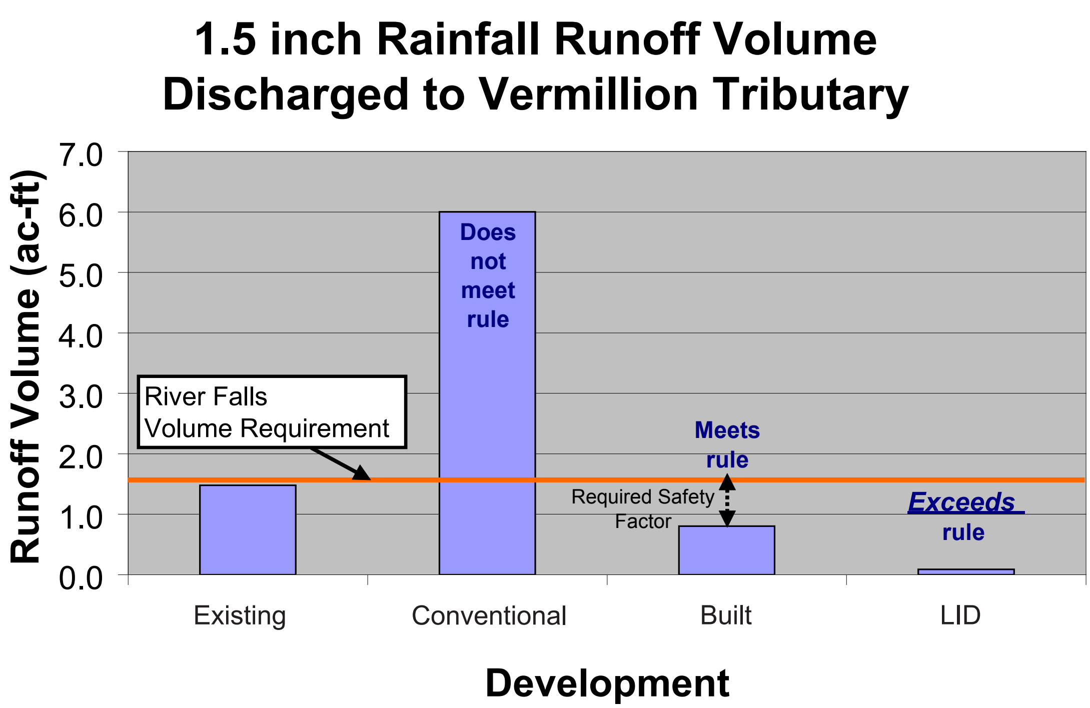


River Falls, WI

The River Falls (WI) ordinances were developed with the intent to provide protection for the Kinnickinnic River and its tributaries, a valuable Wisconsin trout water of regional significance. The stringent rules and standards developed by the City of River Falls presented a good ruler by which to measure the protection provided by the three development scenarios.

All three development scenarios met and exceeded the River Falls stormwater rate control standards which required maintaining pre-development peak rates from the 2, 10, and 100 year 24 hour events. This is as expected since conventional stormwater features (and newer modifications) were developed with the intent of meeting peak discharge rates. In this particular case, the peak discharge rates were significantly reduced, even further beyond pre-development peaks, as was required by the local Water Management Plan. However, even if such strict local restrictions were not in place, conventional and LID alike would be expected to meet the River Falls rate controls.

Both the Built and LID development scenario complied with the volume control portion of the River Falls rules. The River Falls rules require infiltration of additional runoff over pre-development conditions of the 1.5 year event with a safety factor of two. The conventional development stormwater features provide zero volume control and, therefore, did not meet the volume rule. The built scenario, which provides volume control by a regional infiltration basin is on the cusp when considering the safety factor. The LID scenario exceeds the rule requirements. The River Falls volume requirements are represented in Graph 9.



NPDES/SDS MS4 Nondegradation

NPDES/SDS MS4 Nondegradation

The MPCA (with EPA oversight) is currently in the process of defining how nondegradation will be implemented and enforced. Draft documentation (MPCA Guidance Manual for Small Municipal Separate Storm Sewer Systems (MS4s), Draft 3/08/06, http://www.pca.state.mn.us/publications/wq-strm4-25b.pdf) notes that "Nondegradation is achieved if 1988 levels of flow and pollutants can be achieved". Selected MS4 responsible for demonstrating change in Storm Water discharge loading will be required to submit modeling that, at a minimum, addresses changes in:

- Average Annual Flow Volume
- Total Suspended Solids,
- and Phosphorus

Modeling will be required to show two time periods; 1988 to Present, and Present to 2020. For those time periods, MS4s will have achieved nondegradation if it can be demonstrated the 1988 average annual flow volume, total suspended solids, and phosphorus levels have been maintained or minimized. It is also noted that actual and precise calculation of loads and volumes are not required. More importantly, relative value computations demonstrating changes among the time periods will be acceptable.

The dominant 1988 landuse of the site was agricultural. Loads computed for annual volume, phosphorus, and TSS are shown in Table 11. The percent change relative to 1988 conditions is shown in Table 12.

In this case, application of the nondegradation criteria applied to the three development scenarios reveals that the TSS and TP requirements have been satisfied by all scenarios. The built and LID scenarios also satisfy the annual volume criteria. The conventional design does not satisfy the nondegradation clause in regards to annual volume.

Table 11: Nondegradation Load Summary

Load	1988	Conventional	Built	LID
Runoff (ac-ft)	577	679	455	230
Phosphorus (mg/l)	470	337	153	27
TSS (mg/l)	344,496	276,058	185,025	93,549

Table 12: Percent Change over 1988 Conditions

Load	1988	Conventional	Built	LID
Runoff	-	18%	-33%	-49%
Phosphorus	-	-3%	-55%	-82%
TSS	-	-20%	-33%	-49%

VRWJPO Draft Standards

Vermillion River Watershed Joint Powers Organization (VRWJPO) Draft Standards

The Crossroads development site that is subject of this comparison is located in the Vermillion River Watershed. No permit rules under the VRWJPO authority are yet (or were) in place during site development. The VRWJPO is currently in the process of developing standards as part of the VRWJPO's Watershed Plan. It is the VRWJPO's intent, following Plan amendment, that Rules based on the Standards will be developed.

The three development scenarios were reviewed against the draft Standards (revised 4/12/2006). Relevant Standards reviewed included those pertaining to stormwater management (water quality, temperature, rate control, and volume control). Water quality criteria specifies meeting the standards for the NPDES General Construction Permit issues by the MPCA. See discussion above pertaining to the NPDES Construction Permit. Temperature control language refers to other standards which are set up to address and minimize temperature impacts. Peak rate standards require maintenance of existing 1-yr and 10-yr 24-hr events, as well as, maintenance of 100-year 4-day peak flood flows on the Vermillion River at select locations. Volume control standards specify control of the 2-yr 24-hr runoff volume at pre-development conditions.

All in all, the conventional design failed to satisfy the draft standards (and implied rules) relating to buffers, temperature and volume controls.

The Built scenario moves closer to achieving the intent of the rules, but also fails to meet them on several technicalities. Rate and volume controls placed in the Built design satisfy draft standards such as containment of the pre-development 2-yr 24-hr runoff volume (see Graph 10), but fails to fully comply with specific requirements. For example, under the draft standards, the Built design's infiltration basin would have been required to draw-down the 2-yr runoff volume within 48 hours. As designed, this is not the case.

The LID scenario appears to satisfy all of the VRWJPO Draft Standards

VRWJPO Draft Standards