A Geologist's Perspective on the Red River of the North: History, Geography, and Planning/Management Issues

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INTRODUCTION

In 1974, Arndt and Moran published a geologic report providing baseline information to guide planning in the region of Fargo, North Dakota, and adjacent Moorhead, Minnesota. To most inhabitants of this region, this report today remains obscure. But to regional geologists, Arndt and Moran's report represents a pioneering perspective on knowledgeable, geologic-centered planning within an urban setting in the Red River Valley.

Included within Arndt and Moran's report is a map (Fig. 1) outlining the general construction conditions for all of Cass County, ND, and Clay, Co., MN. Dark green is "good," light green is "good-to-moderate," yellow is "moderate," and red is "poor." All of the Fargo-Moorhead metropolitan region lies in a sea of red color.

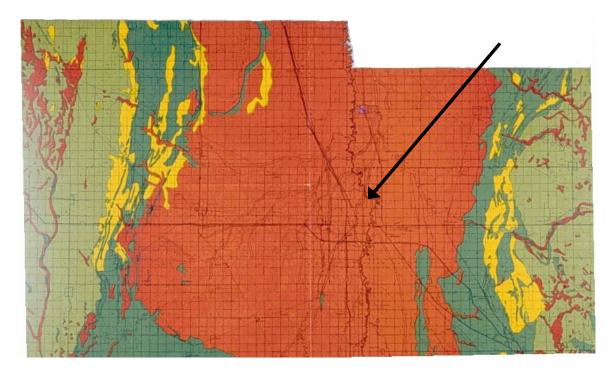


Figure 1. General construction conditions of Cass County, North Dakota and Clay County, Minnesota (from Arndt and Moran, 1974). East-west distance across map is approximately 115 km (71 miles). The arrow points to the Fargo-Moorhead metropolitan region.

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One does not find the map of Arndt and Moran displayed prominently in the lobby of a local Chamber of Commerce. Nevertheless, what they present remains today a realistic view of the geologic challenges of development and land management in the Red River Valley. In a historical perspective, it would have been better if Fargo, let's say, had first been established at a site closer to Tower City, ND. Likewise, it would have been better if Moorhead had first been established closer to Hawley, MN.

But, Fargo, Moorhead, and other cities in the Red River Valley are geographic facts. We cannot expect to move these cities to well-drained sites supported by stronger earth materials. All cities in the Red River Valley are nonetheless highly prone to geologically-induced damage. This damage, while to some degree inevitable, can be mitigated through improved planning and land management.

The lessons to be learned are simple but profound. Through improved public education on the geologic challenges of human settlement in the Red River Valley, policies can be established to accommodate (and to provide some level of sense and safety) development on this terrain. This paper outlines some of the perspectives central in such education at all levels.

A GEOLOGIST'S OVERVIEW OF THE PROBLEMS

The Red River Valley of North Dakota/Minnesota is the youngest major land surface in the contiguous United States, having been subaerially exposed upon the final regional drainage of the waters of Glacial Lake Agassiz about 9,200 years ago. Therefore, whereas most river systems in the United States date in ages in the millions or even tens of millions of years, the present course of the Red River of the North is only a few thousands of years old.

Underlying the Red River Valley are soils that induce both great agricultural activity and challenging geotechnical conditions. These soils are developed on a wedge of smectitic clays and silty-clays derived predominantly from late-glacial erosion and reworking of Cretaceous shales and dispersed as suspended sediments into Lake Agassiz (it is these clays that form the "red" coloration of Arndt and Moran's [1974] map; Fig. 1). This wedge thickens northward along the axis of the Valley. At Fargo, it is ≈ 32 m (105 feet) thick, with a predictable stratigraphy of 6 m (20 feet) of tan-buff laminated silty-clays of the Sherack Formation underlain by ≈ 26 m (85 feet) of gray, slickensided, fat clays of the Brenna/Argusville Formations (Fig. 2). At the site of the Fargo water treatment plant (data from Midwest Testing Laboratory), typical soil engineering values for the Sherack Formation (depth: $\approx 1 - 6$ m) are: PL = 30, LL = 85, N = 12, and Qu = 3000. For the uppermost Brenna Formation (depth ≈ 8 m), typical values are: PL = 31, LL = 113, N = 6, and Qu = 1370. The high shrink-swell properties of these clays induce foundation shifting, pavement failure, and utility line rupture. Where the sediments are unconfined, their high plasticity leads to slope instability; the valley and channel walls of the Red River and its tributaries are particularly prone to slope failure.

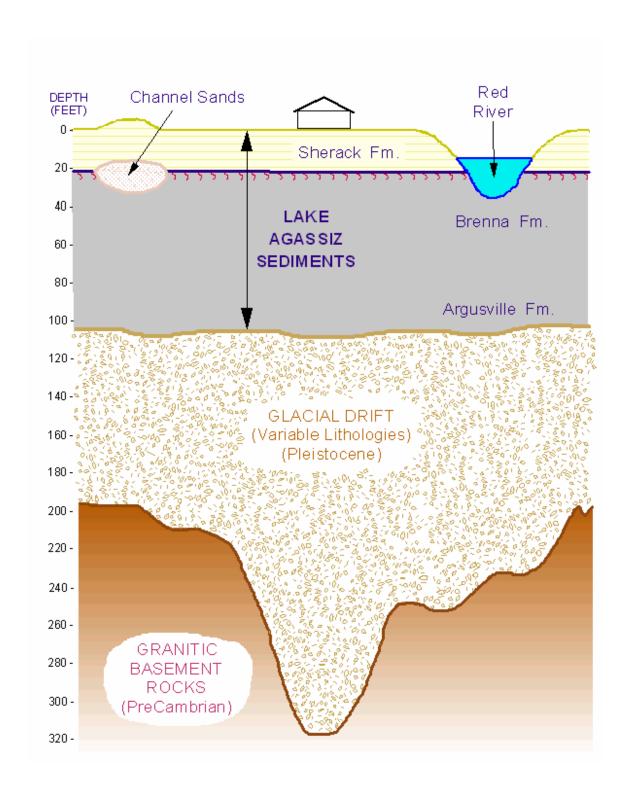


Figure 2. Generalized geologic cross-section of the Fargo-Moorhead region. (Schwert).

The Red River's young age, combined with the low relief and low gradient lake plain over which it flows, induces peculiar floodplain characteristics leading to major flooding:

- The *dynamic* floodplain of the Red River (i.e. the one between valley walls and carved by the river) is only a few hundreds of meters wide and a few meters deep along most of the course of the river.
- The *effective* floodplain of the Red River (i.e. the one covered by waters during times of flood) is instead the flat lake plain of Lake Agassiz, onto which the river easily spills the form of shallow floods of often massive areal coverage.

Flooding is exacerbated by other factors associated with the river and its flow direction:

- Synchrony of discharge with spring thaw: The Red River flows northward. At the same time, spring thaw progresses steadily northward along the Valley. Thus, along the course of the Red River, runoff from the southern portion of the Red River Valley progressively can join with fresh, meltoff from more northerly localities. If this synchrony is perfect (as it was during the major floods of Spring, 1997), the consequences for the northern portions of the Valley can be particularly disastrous.
- **Ice jams:** This factor is likewise related to the northward flow of the river system. Ice derived from the southern Valley progressively meets with freshly-broken ice in the central and northern Valley. In its synchrony with spring thaw, the waters likewise tend to remain frigid throughout its northward flow. Ice concentrations in this regime can easily build up, retarding or damming water flow.
- **Decrease in gradient downstream:** In the region of the southern Valley (Fargo-Halstad), the gradient of the Red River averages 7 cm/km. In the northern Valley region (Drayton-Pembina), however, the gradient drops to 2 cm/km; during times of



Figure 3. Overland flooding in the Red River Valley, north of Fargo-Moorhead, 1997 flood. Shown is the Red River of the North (riparian woodland, lower-right toward upper-left) at its junction with the Sheyenne River (riparian woodland, bottom edge of photo), 1997 flood. View is toward the northeast. (Photo by D.P. Schwert, April 27, 1997).

flooding, the Red River tends to pool, with waters spilling out as a shallow lake that can approach (as in 1997) 80 to 100 km in width.

As was evidenced during the 1997 floods, modeling the progress of a Red River Valley flood event can become a challenging task, exacerbated by coupled flood events of tributary river systems toward the trunk stream. Whereas most flood models have been based on unidirectional flow of tributaries toward the trunk stream, the youth and immature floodplain development of the Red River's tributaries allows each to spill out their waters over extensive lengths of "divides." This spillage (overland flooding) occurs well in advance of their point of junction with larger or trunk streams (Fig. 3).



Figure 4. View northward along the Red River of the North, from Moorhead, Minnesota, 1879. (Courtesy of the Clay County Historical Society).

It is in this setting of inevitable, large-scale floods and of weak, plastic soils that some of the largest cities of northwestern Minnesota and eastern North Dakota were established. These cities developed as agricultural centers at points where the east-west railroad lines crossed the north-south river transportation route (Fig. 4). "The Nile of the Western Hemisphere," is proclaimed for the Valley on the legend on the first geologic map of North Dakota. But, in a geologic perspective, these cities (Wahpeton-Breckenridge, Fargo-Moorhead, and Grand Forks-East Grand Forks) are mistakes – cities that are misplaced on a geologic terrain friendly to agriculture but highly unfriendly to human settlement.

Through popular media, the public tends to apply this term "mistake" to the geologic setting of cities elsewhere: a subsiding New Orleans, an earthquake-prone San Francisco, or a mudflow-prone Los Angeles. But many in the Red River Valley, while likewise

smugly criticizing the geologic settings of cities elsewhere, either ignore or are oblivious to the hazards of their own setting. And this leads to a likewise smug expectation in the Valley that engineering can resolve what problems do occur. Thus, taxpayers have funneled tens of millions of dollars into the Red River Valley for mitigation of damages – much of it wasted or expended unwisely on projects that often will only serve to increase the propensity for flooding or geologic failure. In addition, developers are often encouraged (or, at least, not discouraged) from building on those areas most prone to problems; when problems do occur, those involved with this development are among the first to call for mitigation and compensation.

A GEOLOGIST'S PERSPECTIVE: MASS WASTING ALONG THE RED RIVER AND ITS TRIBUTARIES

Rivers that flow across unconsolidated, fine-grained sediments tend to meander; such is the case, of course, with the Red River. Meanders are dynamic landforms. The higher velocity of river waters passing through a meander tends to be diverted toward the "outside" of the meander loop. With this diversion of velocity is a diversion of the higher stream energy: the outside edges of meander loops typically represent regions of active stream erosion. With the river ever cutting toward the outside edges of its meanders, the channel over time shifts in position. The erosional cliff (cutbank) retreats by erosion and mass wasting, shifting the channel in a direction toward the outside of the meander (Fig. 5).

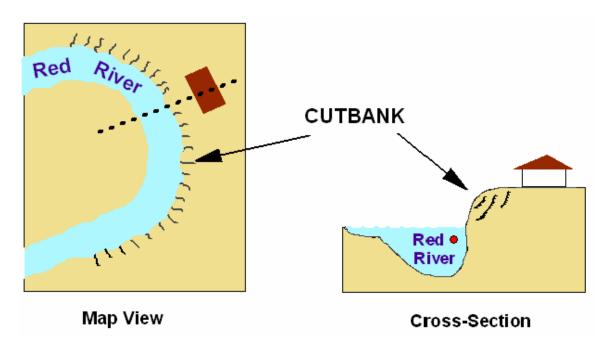


Figure 5. Map view and cross-section of a meander loop along the Red River of the North. Red dot in cross-section represents the approximate zone of highest velocity (energy) for river flow.

In the Red River Valley, where weak sediments are unconfined (for example, exposed "on edge" along a meander or valley wall of a river), they are highly susceptible to failure. Several types of slope failure are common:

Rotational Slump

Slump is common where clay-rich materials are exposed along a steep slope. Such oversteepened slopes occur naturally on the outside of meanders along the Red River. Slump is typically identified as the downward movement of a block of earth material along some curved surface of failure (Figs. 6 and 7). Rotation of the slump block during movement generally takes place, and trees and other features are rotated with the block. The process can be rapid, exacerbated by enhanced soil moisture conditions.

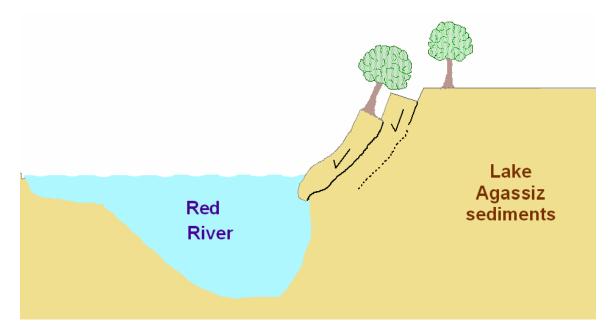


Figure 6. Cross-sectional model for rotational slump along the Red River of the North. Cutbank is to the right side of the channel in this diagram.

Figure 7. Rotational slump along Red River of the North in Fargo, North Dakota. Note the relationship of this activity to the cutbank and the outside of the river meander (left). (Photo by D.P. Schwert).



Flow Slump

Related to slumping is another process evident along some slopes bordering the Red River and its tributaries. Here, instead of the block rotating downward, it drops almost vertically (Figs. 8 and 9). The occurrence of this process is frequently evidenced by a terrace-like appearance along the slopes. Unlike rotational slump, trees and other features on the displaced block continue to stand vertically. This mass wasting process appears to be the result of the horizontal flow of weak clays toward the channel. As the clays are squeezed into the channel, the overlying ground drops vertically. Like rotational slump, the flow slump process can be both rapid and is accelerated by high soil moisture conditions.

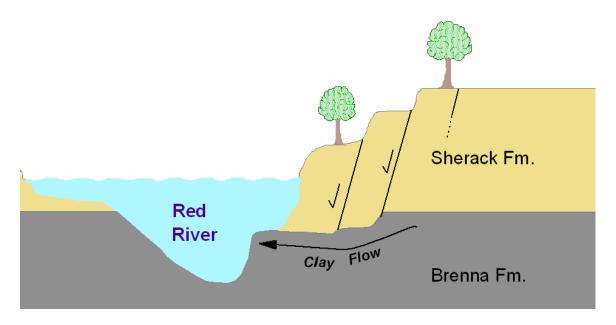


Figure 8. Cross-sectional model for flow slump along the Red River of the North. Cutbank is to the right side of the channel in this diagram.

Figure 9. Flow slump along the Red River of the North near Hendrum, Minnesota. River cutbank is to the left of this view. Note the vertical position of the trees, the bases of whose trunks had likely been even in elevation with the field during the previous year. (Photo by D.P. Schwert).



Creep

Creep is the imperceptibly slow, downslope movement of soil and earth materials. Unlike slump, the rates of creep seldom exceed a few centimeters of movement per year, but the inevitability of creep can severely impact shallowly-placed structures. Where emplaced upon slopes, sidewalks, walls, and landscaping can be displaced or destroyed by creep (Fig. 10).

Figure 10. Creep along the Red River of the North at Trollwood Park, Fargo, North Dakota. Note the fractured pavement and tilted fenceposts, plus relative position of this setting on the outside (cutbank) of a Red River meander. (Photo by D.P. Schwert).



Earthflow

Earthflow is the downslope movement (flow) of a mass of earth materials, typically resulting in a lobe-shaped landform (Fig. 11). Development of earthflow lobes in the Valley are localized and usually coupled with extremely high soil moisture conditions.



Figure 11. Earthflow on cutbank region of Red River of the North near Trollwood Park, Fargo, North Dakota. (Photo by Barry Olson).

To summarize, lands bordering the outside margins of meander loops are inherently unstable. Yet residential and commercial development in the Red River Valley continues on these vulnerable land surfaces, with much of the development occurring directly on the most problematic regions of meander development.

Rates of slope retreat are difficult to predict. Aside from the rate of erosional processes induced by the river, they are also tied to:

- Soil moisture conditions (rates have increased dramatically since 1993, when the "late 1980's" drought ended), inducing high plasticity in the clays.
- Water levels in the river (higher water levels tend to induce a positive hydraulic pressure against the river bank, retarding the movement of earth materials. channelward. Likewise slope failure is accelerated during times of low water levels, particularly if the clays have high plasticity).
- The actions of man (removing stabilizing vegetation, adding houses and other load on top of the slope, introducing water on and into the affected slope areas, etc.).





Figure a

Figure b



Figure c Figure d

Figure 12. Crestwood Division in south Moorhead, Minnesota. **a.** View of neighborhood south of 52nd Avenue bridge, yellow arrow points to white house; **b.** back yard of white house in 1995; **c.** same view in 1997; **d.** removal of white house (and neighboring houses) in 1999.

The author can point to numerous examples of new housing in the Red River Valley permitted for construction into highly prone areas (e.g. Fig. 12). The pattern is predictable: a new house is constructed on high ground overlooking the outside (cutbank) of a meander. Its owner clears trees and other vegetation, so as to allow an unobstructed veranda of lawn from the house down to the river. A pump is often placed into the river so that the owner can continuously water the lawn on this slope using free water from the river. In rural sites, a sewage drain field generally underlies the lawn.

In this scenario, weight is added to this cutbank slope both by the house and by the addition of water. With the water, as well, is an increase in the plasticity of the clays. Slope retreat (already inevitable) rapidly accelerates. Mitigation is economically unfeasible. The owner cries "victim," and taxpayer dollars are utilized to buy the homeowner out – usually at close to 100% of value. The houses are removed, and the land is abandoned. In the meantime, new housing is permitted onto similar settings further down the river.

A GEOLOGIST'S PERSPECTIVE: FLOODING ALONG THE RED RIVER AND ITS TRIBUTARIES

Following the 1997 floods, much finger-pointing occurred as to who or what was to blame for this event. There was a call for enhanced wetland restoration, the construction of flood protection dams, and new and higher dikes. Three obvious points, however, were largely ignored in all of this discussion:

- 1. A great flood in 1997 was inevitable, and wetland restoration or dams would have done little to mitigate the magnitude of this particular event.
- 2. The 1997 flood could have been much larger in magnitude, and floods in the future certainly will be.
- 3. The Red River *needs* to flood, and planning and development should occur so as to allow the river to deliver its water with little constriction, obstruction, or impedance.

This third point (a *need* to flood) is crucial to wise land management and planning, yet it is repeatedly ignored in addressing regional floodplain management. This point is easily addressed by working to provide accommodation for the flood waters: minimal confinement of flow, coupled with maximization of the river's natural storage capacity. But, it is repeatedly abused, as per these examples in the Fargo-Moorhead region:

Example: Elimination of Natural Storage

Following major Red River flooding in 1969, there was extensive removal of affected buildings and structures from flood-prone areas. These lands, some involving entire neighborhoods, were converted into floodable parklands and parking lots. The plan was wise and visionary, in that it accommodated the movement and storage of flood waters passing directly through the heart of an urbanized region.

Since that time, however, there have progressively been efforts to "flood protect" these floodable lands. Post-1969 dike construction "protects" riverside golf courses (Fig. 13)



Figure 13. This low dike (ridge between the obelisks) along Elm Street in north Fargo, North Dakota, was constructed in 1979 as flood protection for a small city golf course. It is but one example of the removal of flood storage in favor of the parklands. (Photo by D.P. Schwert).

and ball fields from flooding. A temporary dike in downtown Fargo "protects" what should be a floodable parking lot adjacent to City Hall.

In north Fargo and north Moorhead, considerable residential development has been accommodated by filling in lands that were part of the natural floodplain of the Red River. The practice continues today, exemplified by new residential development accompanied by current infilling of floodplain lands along 15th Avenue in north Moorhead – lands that were flooded (and therefore served as temporary water storage) for the 1997 and earlier floods.

Every cubic meter of floodplain water storage removed through these actions is a cubic meter of water that must be displaced elsewhere – with the general impact of exacerbating flood conditions upstream of these sites through constriction of the flow of the river.

Example: Obstruction of Natural Flow

Two low-level bridges have been constructed in recent years across the Red River in the Fargo-Moorhead region. For purposes of esthetics and economies, the bridges have been designed a floodable. But each bridge provides a >2 m vertical obstruction across the entire floodway of the river. They act as choke points for ice flows and floating trees,

further enhancing to increase the propensity and level of flooding upstream of these bridge points (Fig. 14).



Figure 14. Ice and debris jam upstream of the low-level 12th Avenue North toll bridge, Fargo, North Dakota, 1995. (Photo by D.P. Schwert).

In addition, a number of these dikes constructed to "protect" Fargo-Moorhead's parklands and parking lots are, themselves, man-made obstructions inhibiting the efficient flow of floodwaters through the heart of this urbanized region.

Added to all of this is a mismanagement of statistics provided to the public:

- The 1897 Red River flood was eventually labeled as a "500-year" flood event but how could it be, given <100 years of statistical river data?
- The 1969 Red River flood was labeled as a "500-year" flood event but how could it be, given <100 years of statistical river data?
- The 1997 Red River flood was labeled as a "500-year" flood event but how could it be, given about 100 years of statistical river data?
- The Summer, 2000, rainfall in Fargo was labeled as a "300-year" precipitation event but how could it be, given about 100 years of statistical precipitation data?

In short, the public is presented with dubious statistics, usually in some official form, as if that particular flood event is a perturbation that cannot be reasonably expected to have ever occurred . . . or to ever occur again. But, major flooding is a regular part of the hydrologic regime of the Red River Valley, and planning should occur so as to not inhibit it but to accommodate it.

A GEOLOGIST'S PERSPECTIVE: ACCOMMODATING BOTH HUMAN SETTLEMENT AND THE GEOLOGIC CHALLENGES OF THE RED RIVER VALLEY

A principle that I try to reinforce in my geology courses is: "Often the most efficient approach to resolving a geologic problem is to avoid the problem altogether." Much of the damage induced by slope failure and by flooding is easily preventable by keeping all residential and commercial development away from prone areas. The floodplains and lands adjacent to these rivers are maintained as greenbelts, accommodating multiple (and floodable) lands for recreation and wildlife protection. Dike construction is minimized and held away long distances from the river itself, so as to accommodate the storage and movement of floodwaters.

This concept, however, appears to go against the existing grain of approaches to planning and land management in the Red River Valley. Instead, the approach has been (and, sadly, continues to be) residential and commercial development up to the flanks of the river, itself. Recent actions by Cass County, ND, Planning Commission, however, to zone a construction-free buffer adjacent to river systems provide some hope.

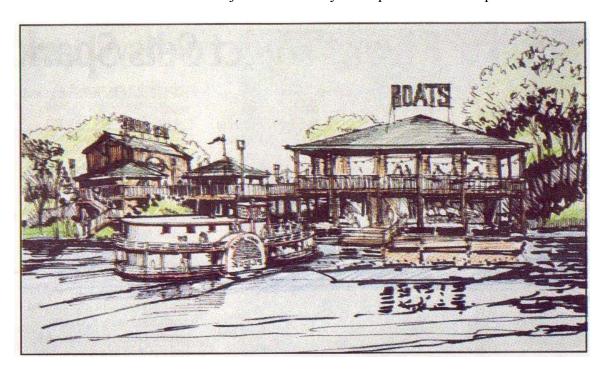


Figure 15. Proposed riverfront development for Fargo, from the 1989 RUDAT report. All of the structures proposed for this "visionary" project would have been totally immersed by waters of the 1997 flood.

In 1989, amidst much public heraldry, a RUDAT ("Regional Urban Design Assistance Team") presented their proposal for riverfront development and land use in the Fargo-Moorhead region. The RUDAT report was acclaimed by community leaders as visionary, and showed the transformation of the riverfront downtown (Fig. 15) into an

environment akin to that of the River Walk area of San Antonio. But Fargo geologically is not San Antonio, and the Red River is hydrologically not the San Antonio River. The buildings and other permanent infrastructure envisioned by RUDAT in 1989 to border the river would have been inundated by 6 m of floodwaters in 1997. Finally, the RUDAT report itself made no mention of the engineering challenges of maintaining the stability of such structures on weak, plastic soils.

Following the 1997 flood, the city of Fargo has worked to remove flood-prone housing adjacent to the river. However, the city is now (2003) considering a new city hall, city library, and other buildings on lands immediately *adjacent* to the channel (and lands from which buildings were removed following the 1969 flood). Through such actions, planners fail to provide examples of sound floodplain zoning and management. Some will argue that they can protect this building complex through a system of floodwalls, but no consideration is given as to furthered channel constriction, permanent loss of water storage, and enhanced flooding levels upstream that will likely be a consequence of such downtown development.



Figure 16. 1997 flood of the Red River of the North, south of Fargo, North Dakota. This photo shows planning and land management at its worst. Note the placement of new housing: 1) on flood-prone lands, and 2) on the vulnerable slope positions overlooking erosional cutbanks of stream meanders. (Photo by D.P. Schwert).

In new construction, the wisdom of accommodating to geologic factors could go even further. The expansive clays of the Red River Valley, coupled with their inability to efficiently drain, make basements a prime cause for both structural and flood damage. For all new construction, banning basements and forcing each building to rest on an amply-thick platform of well-drained aggregate could (together with river-buffered

zoning) relieve nearly all of the geologically-induced damage in the Red River Valley. For purposes of storms, each building would be equipped with a strong internal space for temporary shelter. This simple solution would also effectively reduce radon accumulations – another geologically-induced problem of the Red River Valley plaguing basements, and so far unmentioned in this report.

CONCLUSION

Cities like Wahpeton-Breckenridge, Fargo-Moorhead, and Grand Forks-East Grand Forks are geologic mistakes – but geographic facts. Given that these cities will never be moved in their entireties, there are still ways of accommodating to the geology and mitigating the damages induced by flooding and slope failure. However, these require a basic understanding and acceptance of the inevitability of these geologic processes.

In planning, we should not be working toward conserving the past of these cities – instead, through wise planning and land use, we should work toward conserving their futures.

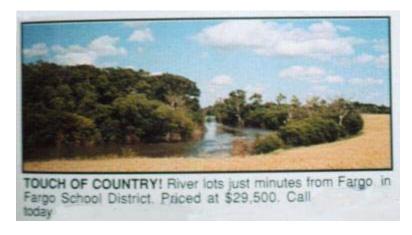


Figure 17. Real estate advertisement from a Fargo publication. With sensible regulations, development in this type of prone geologic setting would no longer be permitted.

REFERENCES

Arndt, B.M. and S.R. Moran, 1974, Physical data for land-use planning - Cass County, North Dakota, and Clay County, Minnesota: North Dakota Geological Survey Report of Investigations No. 54, 16 pp. + 9 maps.