# Construction of a Lineament Density Map with ArcView and Avenue

Gyoo-Bum Kim

**Abstract**

To study the relationship between deep groundwater productivity and lineament, we use several lineament maps which are lineament map, lineament length density map, lineament cross-point density map and others from Remote Sensing. The avenue script files for calculating the lineament statistics, the lineament length density, lineament cross-point density value and the distance between a groundwater well and the nearest lineament are developed with Avenue™ language in ArcView 3.2 GIS software. We find that it is very easy to calculate these lineament related values with script files and also they are useful for drawing the lineament density maps in ArcView GIS software.

*Keywords:* Hydrogeological map; Lineament; Lineament density map; ArcView; Avenue™

## 1. Introduction

Basic information on groundwater yield and contamination should be accumulated for systematic management and uses of groundwater resources. In December 1993, the Korean government established the "Groundwater Law" to regulate all kinds of groundwater development activities and to systematically manage the uses of groundwater resources. The provisions of Article 5 in the law require "Basic Groundwater Survey" to obtain basic information on the groundwater resources. The government established a mid and long-term schedule on the survey and has carried it out according to "The Basic Plan for Groundwater Management" in 1996.

There was a need to develop guidelines to unified methods of the basic groundwater surveys, construction of hydrogeological map and thematic maps, and input format of computational data for digital mapping. In December of 1998, the MOCT (Ministry of

Construction and Transportation) and KOWACO issued "The Handbook for the Drawing and Management of Hydrogeological Map". According to the guidelines, hydrogeological map and related thematic maps should include characteristics of groundwater quantity and quality (Table 1).

Table 1. Contents of hydrogeologic map and the related thematic maps (MOCT and KOWACO, 1998)

| Kinds of map | Main contents |
|---|---|
| Main hydrogeologic map | Geology, Geologic structure, Aquifer distribution, Water budget, Sustainable yield, Groundwater level and other aquifer characteristics |
| Water quality map | Investigation well location, Water quality distribution, Electric conductivity, Sources of contamination and other chemical-related factors |
| Lineament map | Distribution of lineament, Lineament density, Well location etc. |
| Depth to water map | Depth to bedrock, Depth to water, Cross section of aquifer, Well location etc. |
| Other thematic maps | Location of water facilities, Well data, groundwater flow pattern, Recharge and discharge area, DRASTIC map, Geophysical survey data, Groundwater use, Surface hydrology, Land use, Vegetation and others |

In this study, we constructed and evaluated script files using Avenue$^{TM}$ programming language, which facilitated output and modification of lineament density and related maps using ArcView GIS software. The ArcView GIS software is useful for various embodiments of ArcView shape file, Arc/Info coverage, Arc/Info grid, Image data, CAD drawings and MapInfo Interchange Format (MIF).

The lineament maps as a thematic map include lineament map, lineament length density map, lineament counts density map, lineament cross-point density map, and other lineament-related maps. The purpose of this study is developing script files which are related to the drawing of three lineament density maps, a lineament length density map, a lineament counts density map and a lineament cross-point density map. We demonstrated the usefulness of these script files for drawing these density maps as a hydrogeological thematic map. Besides the lineament density map, mapping of various other data related to lineament mapping such as distances from lineament to well can also be possible. Using these Avenue$^{TM}$ script files, we can analyze the relationship between wells and lineaments and define the importance of lineaments or lineament density for the branches of well development or groundwater investigations.

## 2. Lineament and related issues

Linear features on surface of the earth have attracted attentions of geologists for many years. This interest has grown most rapidly since the introduction of aerial photographs and satellite image into geological studies. In the early and middle of 1900s, several geologists, Hobbs (1904, 1912), O'Leary et al. (1976), recognized the existence and significance of linear geomorphic features that were the surface expression of zones of weakness or structural displacement in the crust of the earth.

Lineaments have been used in many applications: petroleum and mineral exploration, nuclear energy facility sitings, and water resource investigations. Previous studies have revealed a close relationship between lineaments and groundwater flow and yield (Lattman and Parizek, 1964; Mabee et al., 1994; Magowe and Carr, 1999; Fernandes and Rudolph, 2001). Generally lineaments are underlain by zones of localized weathering and increased permeability and porosity. Meanwhile, some researchers studied relationships between groundwater productivity and the number of lineament within specifically designated areas or lineament density rather than the lineament itself (Hardcastle, 1995). Therefore mapping of lineaments closely related to groundwater occurrence and yield is essential to groundwater surveys, development, and management. These lineament maps are constructed as an annexed thematic map of a hydrogeological map in Korea (MOCT and KOWACO, 1998).

## 3. Development of Avenue™ scripts for lineament maps

The Avenue™ language is a programming language for ArcView GIS software and we can easily manipulate the ArcView functions and tools. With Avenue™, we can customize the way ArcView looks, modify ArcView's standard tools, create new tools, integrate ArcView with other applications and develop and distribute the custom applications on top of ArcView.

Especially, Avenue™ is an object-oriented programming language, so it is convenient to use and its application to groundwater analysis is very useful.

In this study, we developed two scripts, "Remove-Node" and "Generalize", to optimize the original lineament map with the Avenue™ scripts. Also, we developed five main Avenue™ scripts, "L-STAT", "Dist-to-Line", "Dist-to-Crosspoint", "L-Selection" and "PL-DENS", for lineament analysis and mapping. The first, "Romove-Node (Remove the lineament's nodes)" is a script to reduce the nodes of lineaments, which are generally produced by digitizing process. With this script, we can optimize the original lineaments and prepare a lineament map for the next process, which is "Generalize" script. The second, "Generalize (Generalize the lineaments)" is a script to produce the best optimized lineament map for analysis. With this script, we can split a large lineament to two or more smaller lineaments by the size of intersection angle, and this then becomes the basic map for lineament analysis. The third, "L-STAT (Lineament Statistics)" is a script to analyze automatically the orientation of lineaments from the optimized lineament map made by the above two scripts and to get the lineament statistics for the target area. We can draw the orientation histogram or a rose diagram of lineaments using the results from the L-STAT.

The fourth, "Dist-to-Line (Distance to Lineament from well)" is a script to calculate the distance to the nearest lineament from a well and to output this result. The fifth, "Dist-to-Crosspoint (Distance to lineament cross-points from well)" is a script to calculate the distance to the nearest lineament cross-point from a well and to output the result. The sixth, "L-Selection (Extract some specially oriented lineaments from all lineaments)" is a script to classify and extract the oriented lineaments developed along the special directions defined by the user. For example, if we need to extract the extensional lineaments, which were formed by normal fault mechanism or any special oriented lineaments, we use this script. Next, we can apply the PL-DENS to these oriented lineaments produced by "L-Selection" to calculate the lineament density values.

The seventh, "PL-DENS (Calculation of Lineament Length Density Value and Cross-Point Density Value)" is a script to calculate the sum of the lineament length, the number of lineament counts and the number of lineament cross points within circles which are distributed with equi-spaced grids. With this data, we can draw the three kinds of lineament density maps including a lineament length density map, a lineament counts density map and a lineament cross-points density map. These density maps will be used for an analysis of the lineament and well relationship.

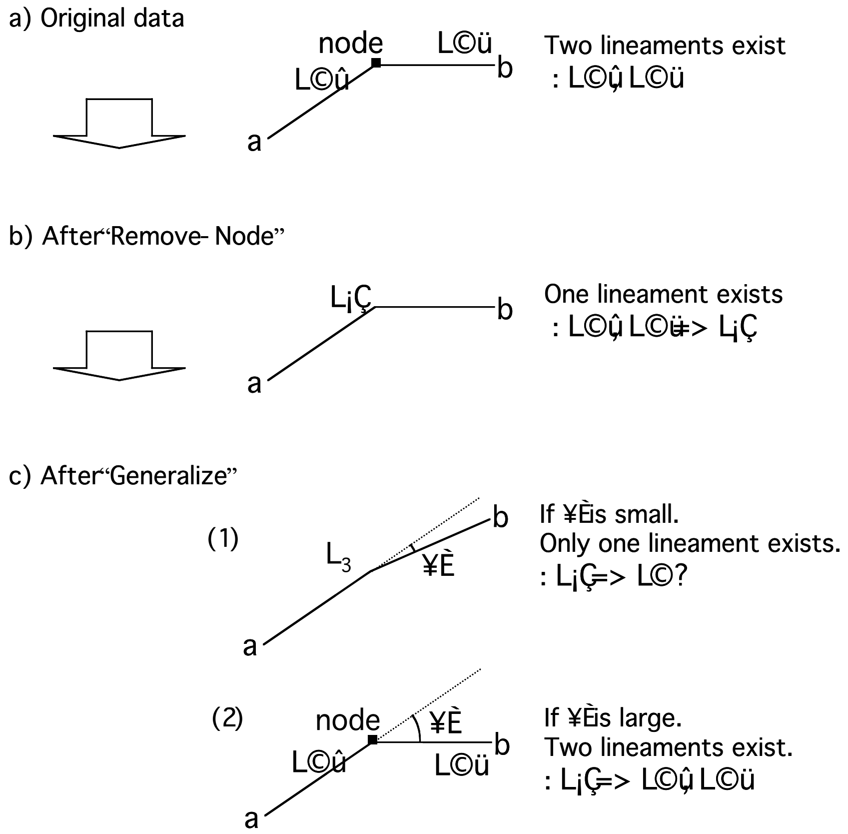
The analysis process is as follows. First, to analyze the lineament density and other characteristics, we prepare an optimized lineament map, calculate the lineament statistics and next conduct a more detailed analysis. Second, to optimize the lineament source data prior to lineament analysis, we use the two scripts, which are "Remove-Node" and "Generalize". We use the "L-STAT" script to obtain the basic statistics including the orientation, the counts, the counts of cross-points and the total length of lineaments for the lineament in the study area. Using the statistical results, we can draw an orientation histogram or a Rose diagram.

Next, we calculate the lineament length density value, lineament counts density value and lineament cross-points density value for equally-distributed circular cells with a "PL-DENS" script. We also calculate the distance from each well to the nearest lineament with a "Dist-to-Line" script and the nearest cross-point of lineaments with a "Dist-to-Crosspoint" script. These scripts can be used to define the relationship between groundwater well production/location and lineaments.

## 4. Preparation of the basic lineament map prior to analysis

We developed the two scripts, "Remove-Node" and "Generalize", to produce a basic standardized lineament map prior to lineament analysis. The original digitized data may have minor errors and be non-standardized as it is conducted manually by input workers or digitized automatically by computer, which may include erroneously duplicated or separated small lineaments.

The duplicated lineaments mean that workers may make mistakes and input the unique lineament twice or three times when digitizing the original map. Generally these lineaments are very short, several meters, as an actual length on a digitized map. If they exist, they are overestimated in calculating the lineament length or counting the number of lineament and the number of cross-points. Consequently this results in an inaccurate lineament density map. So, in this study the duplicated tiny lineaments were removed and optimized by comparing with the original aerial photographs or topographic maps before conducting the lineament scripts. Of course, all errors can’t be removed perfectly but they may be optimized properly for analysis.




a)

| | Shape | From | To | Length |
|---|---|---|---|---|
| $L_1$ | PolyLine | 0 | 1 | 40 |
| $L_2$ | PolyLine | 1 | 2 | 30 |
| | PolyLine | 6 | 8 | 50 |

b)

| | Shape | From | To | Length |
|---|---|---|---|---|
| L¡Ç | PolyLine | 0 | 2 | 70 |
| | PolyLine | 6 | 8 | 50 |

c) (1)

| | Shape | From | To | Length |
|---|---|---|---|---|
| $L_3$ | PolyLine | 0 | 2 | 70 |
| | PolyLine | 6 | 8 | 50 |

c) (2)

| | Shape | From | To | Length |
|---|---|---|---|---|
| $L_1$ | PolyLine | 0 | 1 | 40 |
| $L_2$ | PolyLine | 1 | 2 | 30 |
| | PolyLine | 6 | 8 | 50 |

Fig. 1. The optimizing process of the original lineament data prior to lineament analysis.

The separated lineaments in a digitized map mean that the single lineament is composed of many shorter lineaments because the single long lineament has several nodes (Fig. 1). The digitizing processes create many nodes and show long lineaments as composed of many shorter lineaments because the lineaments are not always straight, but generally curved (Fig. 1a). Lineaments with many nodes may also generate incorrect statistics for lineaments in

ArcView.

If the intersection angle _ between two lineaments, which the user inputs during the "Generalize" script, is very small, such as 5°, the node point can be regarded as a inflection point of a long curved lineament. In this case, two lineaments should be summed up and changed to a single lineament (Fig. 1c-1). On the contrary, if the intersection angle _ is large, they may be originally different and can be divided into separate lineaments (Fig. 1c-2).

To calculate the angle between two lineaments, the "Law of Cosines" is used. For a triangle with sides a, b, and c and the angle C opposite the side c, the cosine law says:

$$c^2 = a^2 + b^2 - 2ab\cos C \qquad (1)$$

and,

$$\cos C = [a^2 + b^2 - c^2]/2ab \qquad (2)$$

$$C = ar\cos\{[a^2 + b^2 - c^2]/2ab\} \qquad (3)$$

So, we can calculate the angle between two lineaments, X.

$$X = 180 - C \qquad (4)$$

## 5. Calculation of lineament values

### *5.1. Lineament statistics: L-STAT*

Prior to lineament analysis, we need to know the lineament characteristics, which include orientations of lineament, mean of lineament length and number of lineament. We developed the script, "L-STAT", for calculating the lineament statistics from the basic lineament map that is constructed by the processes using the two scripts, "Remove-Node" and "Generalize".

The main code of "L-STAT" is shown in Fig. 2 and the structure of output file is shown in Table 2. As shown in the "L-STAT" code, to calculate the total number of cross points of lineaments, a rectangle with the area that is (gridsize)_with the coordinates of left-bottom with (x, y) and right-top with (x+gridsize, y+gridsize) is made at each node point preferentially and next the intersection data of lineaments are saved as a new database.

*1) Calculate the total number of lineaments*

```
linecount = linetab.getselection.count
```

*2) Calculate the total number of Cross Points of lineaments*

```
crosscount = 0
for each x in leftxcood..rightxcoord by gridsize
  for each y in bottomycoord..topycoord by gridsize
    selRect = Rect.MakeXY(x, y, x+gridsize, y+gridsize)
    thetheme.SelectbyShapes(selRect, #VTAB_SELTYPE_NEW)
    for each line in thetheme.GetSelection
      ptlist = l.PointIntersection(ll)
      for each n in ptlist
        crosscount = crosscount + 1
      end
    end
  end
end
```

*3) Calculate the total length of lineaments in target area*

```
for each r in theAllRecords
  aline = linetab.returnvalue(shapefield, r)
  linelength = aline.returnlength
  linesum = linesum + linelength
```

*4) Calculate the length of lineament and the number of lineament within each angle ranges*

```
  lineslope = linedx / linedy
  atanv = lineslope.atan
  lineangleatan = 90 - ((atanv*180)/3.14159265358979)
  if (lineangleatan < 0) then
    lineangleatan = 90 - (180 + lineangleatan)
  end
  oldval = newdbasetab.returnvaluenumber(cntfld, 0)
  oldlength = newdbasetab.returnvaluenumber(lengthfld, 1)
  newdbasetab.setvaluenumber(cntfld, 0 , oldval + 1)
  newdbasetab.setvaluenumber(setfld, iii + 1 , oldlength + linelength)
end
```

Fig. 2. The main code and description of L-STAT script file.

Table 2. Table structure and an example of output file produced by L-STAT script

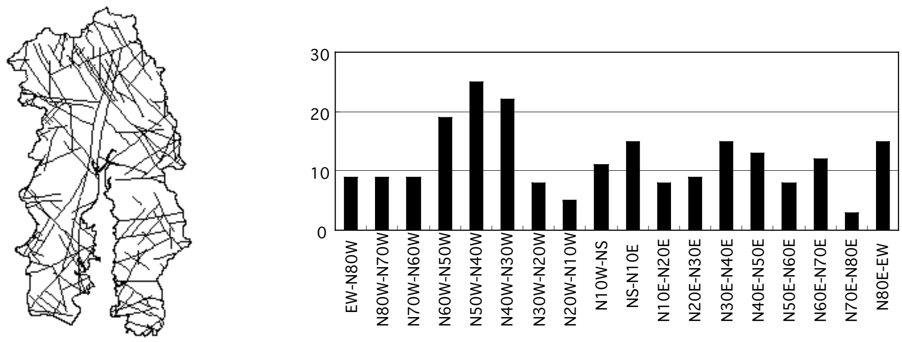
| *ID* | LENSUM | CNTSUM | INTERSECT | 90 ~80 | 80 ~70 | 70 ~60 | 60 ~50 | .... | -70 ~-80 | -80 ~-90 |
|---|---|---|---|---|---|---|---|---|---|---|
| Counts | - | 638 | 1277 | 23 | 15 | 47 | 59 | .... | 16 | 17 |
| Length | 890278.26 | - | - | 27575 | 29358 | 46171 | 82367 | .... | 17604 | 16802 |

It is seen in the table that the output involves total counts of lineaments, total length of lineaments, total counts of lineament cross-points, and the directional statistics, from N90°W to N90°E, including length and count of lineaments. In Fig. 2, the interval of the angle for directional statistics is 10° and generally the user can input this interval. From this, we can calculate the density of lineament for angle interval and length of lineament divided by number of lineament.

Table 3. Results of optimizing lineaments with two scripts (the reference angle for "Generalize": 20°)

| Counts of lineaments | Kangjin district | Youngam district |
|---|---|---|
| District area (km$^2$) | 494 | 553 |
| Original lineament data | 252 | 360 |
| After "Remove-node" | 204 | 286 |
| After "Generalize" | 215 | 307 |

a) Kangjin district




b) Youngam district

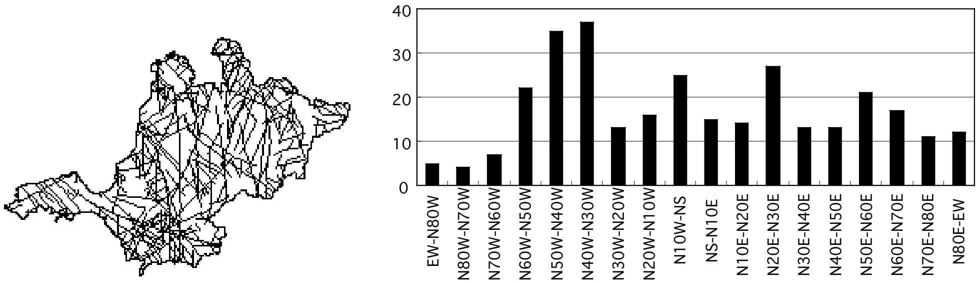



Fig 3. Example of lineament maps for 2 regions: Kangjin and Youngam districts produced by "Remove-node" and "Generalize" scripts and examples of lineament histogram drawing using the output data from the "L-STAT" script.

Table 3 and Fig. 3 show optimization results and an optimized lineament map produced by the two scripts, "Remove-node" and "Generalize" and changes in the count of lineaments using these two scripts for 2 districts within Korea: Kangjin, and Youngam. With the "L-STAT" script, we can calculate the overall lineament characteristics, the number of lineaments and the total length of lineaments and discover the outline of lineaments in study area. Directional distribution of lineament by orientation histogram shows the major and minor direction of lineament and the extension of lineaments.

*5.2. Extraction of lineament with special directions: L-Selection*

Caponera (1989) interpreted the remote sensing image for groundwater surveying and extracted the morphology, lineaments, structural features, vegetation, drainage from the image. His study concluded that the tensional fractures by tectonism are related to the groundwater storage or movement in bedrock. Travaglia (1989) also studied the fracture and groundwater exploration in two areas, the Bayhan Al Qasab area (Yemen) and the Philippines. He also revealed that the tensional fractures (N10$^{o}$W and N15$^{o}$~25$^{o}$E directions) are related with groundwater exploration in the Karst region, Philippines. Sidle and Lee (1995) concluded that anisotropic hydraulic conductivity was related to the orientation of geologic structures. Larson (1972) indicated that wells located in fractures which were interpreted as extensional fractures were much more productive than wells located in shear fractures.

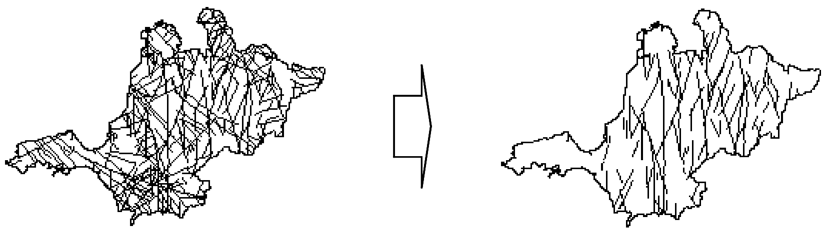
Continuous multiple tectonism and shear mechanism can change the previous geometry of fractures, so it is difficult to define the total fracture mechanism and to extract the extensional fractures. But, if we know the tectonic history and define the extensional fractures, we can try to reveal the relation between lineaments or extensional lineaments and groundwater productivity. Recently groundwater development in a fractured rock is common in Korea. Fracture zones characterized by high transmissivity generally generate the high groundwater production area but it is very problematic to identify these highly productive fractures. Structural analysis and tectonic history study can provide useful information for this problem in regional scale studies.

1) *Extract and save the lineaments with the special orientation ; minang means the minimum input angle value and maxang means the maximum input angle value*

```
for each r in theAllRecords
  line = lineTab.ReturnValue(shapefield, r)
  lineStartPt = lline.ReturnStart
  lineEndPt = lline.ReturnEnd
  ldx = lineStartPt.GetX - lineEndPt.GetX
  ldy = lineStartPt.GetY - lineEndPt.GetY
  lineslope = ldx / ldy
  ang = (lineslope.Atan * 180)/3.14159265358979
    if ((minang < ang) and (maxang > ang)) then
    newrec = newlineFtab.AddRecord
    newlineFtab.SetValue( shapefield, newrec, line)
    end
end
```

Fig. 4. The main code and description of L-Selection script file.

a) Youngam district




b) Kangjin district

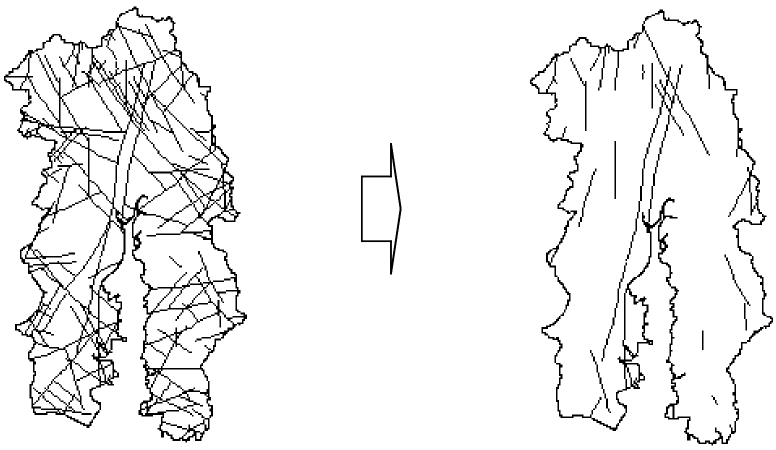



Fig 5. Examples of lineament extraction with special strike orientations, from N30°W to

N30°E, using L-Selection (n: counts of lineaments).

The purpose of "L-Selection" script is to produce the distribution map of directional lineaments which the user can voluntarily select from the study of tectonic history and deformation process, especially extensional directions, to define the above phenomenon that the fractures produced by extensional tectonism are much more related to groundwater production. "L-Selection" script is useful in ArcView for extracting these lineaments. A lineament map made by this script can be used to analyze the relation between lineaments and groundwater using the "PL-DENS" script.

The main code of the "L-Selection" is shown in Fig. 4. The user inputs the range of angle for lineament extraction, which means the strike angle with extensional characteristics, from -90 (N90°W) to 90 (N90°E). Fig. 5 is an example of script performance with a strike angle of from -30 to 30 in the Youngam and Kangjin districts in Korea. We can find the change in the number of lineament from 307 to 110 in Youngam and from 215 to 56 in Kangjin. In the same manner, lineament length and cross points included in the range of the strike angle can be computed using this script.

### *5.3. Lineament density calculation: PL-DENS*

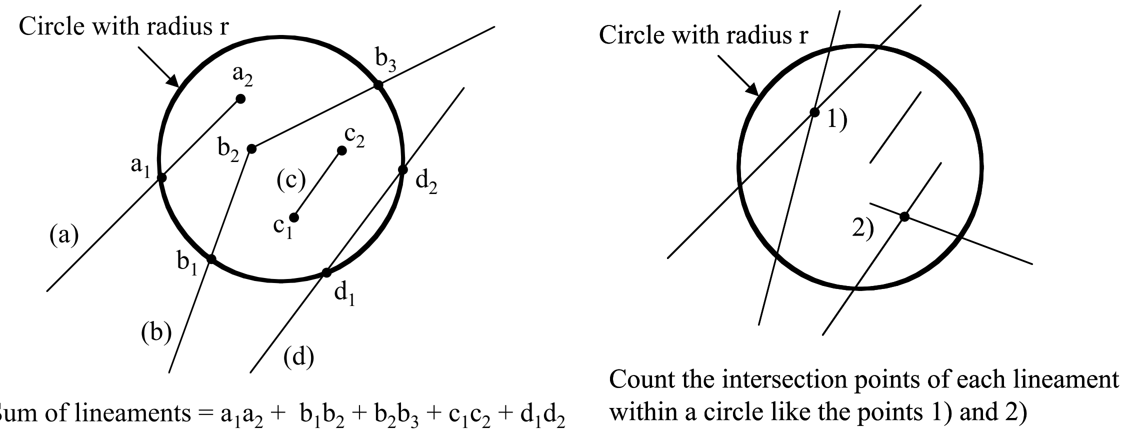
A script "PL-DENS" computing lineament length density value, counts density value and cross-points density value was developed using Avenue™ language and its applicability based on lineament map from remote sensing was evaluated. When constructing the three lineament density maps, firstly lineament length density values, counts density values and cross-points density values are computed using this script file. After calculating these density values, a lineament length density map, a lineament counts density map and a lineament cross-points density map are constructed based on the computed values using commercial ArcView or Surfer programs.

A computing method for lineament density values can be referred to Hardcastle (1995). The equi-spaced grids are drawn on the lineament map and circles with a given radius are constructed at each node. Now the length, counts and cross-points of lineaments within the circle are summed and the values are given to each node (Fig. 6). The calculation of the lineament length is based on the distance ($c_1 \sim c_2$) between apexes within the circle (Fig. 6a). In the case of an intersection between a circle and a lineament, the intersection is converted to apex and then the distance ($a_1 \sim a_2$) is calculated. Fig. 7 shows the main code of the PL-DENS script to produce the three lineament density values.

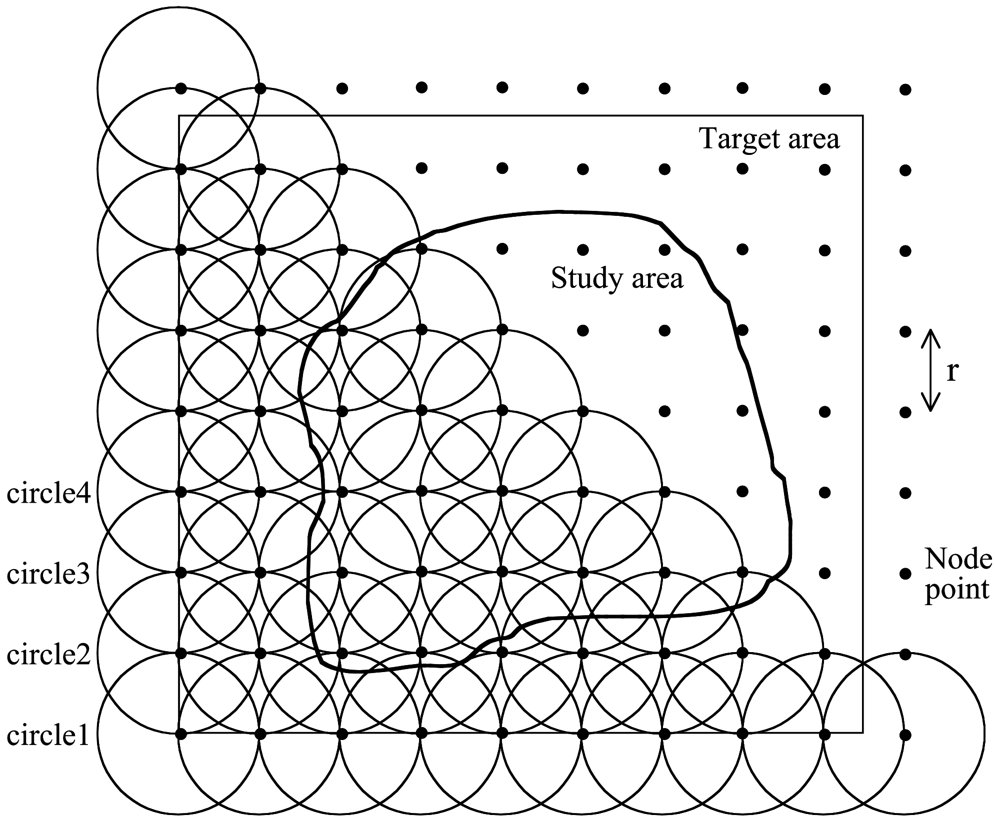
A summary of the operating procedure for the PL-DENS script file when constructing lineament density maps is shown in Fig. 8. If an optimized lineament map, which is produced by the "Remove-Node" and "Generalize" processes, is prepared, then we select the target area and input the radius of circle. After this, the calculation process of a lineament density values can be done. An extensional lineament map made using the "L-Selection" script can be created with the same method. Here it is necessary to select the best or optimum radius of the circle related to lineament density. After the lineament density value is computed, each node can be represented on a view using the "Add event theme" menu in ArcView. The attribute table, showing lineament length value at each node, can be examined.

Table 4 shows the basic structure of an output file produced by PL-DENS script. The first field, shape, is the data type and the next field, ID, is the series number of the node point. X-coord and Y-coord are the center of each circle. LENSUM means the sum of lineament length and LENDENS means the lineament length density within the circle, which is the lineament length divided by the circle area (unit: km/km$^2$). CNTSUM is the total number of lineaments and CNTDENS is the total number of lineaments divided by the circle area (unit: n/km$^2$). INTERSECT is the total number of cross points of lineaments and INTERDENS is the total number of lineaments cross points divided by the circle area (unit: n/km$^2$). The lineament counts and lengths included in each interval of strike angle are calculated and then stored in the output table.

Using the lineament length density value (LENDENS in Table 4), the lineament counts density value (CNTDENS in Table 4) or lineament cross-points value (INTERDENS in Table 4) at each node, the three kinds of lineament density maps can be drawn with AcrView's extension or the other tools such as Surfer. Fig. 9 shows an application of the PL-DENS script in developing lineament length density map as a thematic map in a hydrogeological map for 2 districts: Youngam, and Kangjin in Korea. Like the lineament length density map, the lineament count density map and the lineament cross-points density map can be drawn with this script and ArcView software.




a) Calculation method of total length and cross points of lineaments in a circle




b) The arrangement of the squared nodes and the related circles with radius r and interval r (revised from Hardcastle, 1995)

Fig. 6. The calculation method of lineament length and cross-points in a circle and the

arrangement of each circle.

1) *Select target are using Rectangle draw in ArcView and compute horizontal and vertical length using rectangle apexes*

```
therect = theview.getgraphics.get(0)
therectlist = therect.getbounds
rectminy = therectlist.getbottom
rectminx = therectlist.getleft
rectmaxx = therectlist.getright
rectmaxy = therectlist.gettop
xlength = rectmaxx - rectminx
ylength = rectmaxy - rectminy
```

*2) Input radius of circle (node space)*

```
kkdist = msgbox.input("X-Distance of selected area is " + xlength.asstring + " Meter" + nl +
        "Input the Radius of Analyze circle ","Radius Input","500")
```

*3) Define start point of node and add 1 to length and height*

```
startpini = rectminx@rectminy
xint = (xlength / kkdist.asnumber).abs + 1
yint = (ylength / kkdist.asnumber).abs + 1
```

*4) Construct circle with center of startp and radius of kkdist*

```
kkcircle = circle.make(startp,kkdist.asnumber)
gc = graphicshape.make(kkcircle)
gc.SetSelected(TRUE)
gc.setdisplay(thedisp)
theView.GetGraphics.Add(gc)
```

*5) Store the circle to variable theSRCshape and select thematic element (lineament)*

```
theSRCshape = gc.getshape
thetheme.SelectbyShapes(theSRCshape, #VTAB_SELTYPE_NEW)
theftab.updateselection
```

*6) Segment to sum up the lineament length within the circle*

```
for each Selrec in theftab.getselection
av.showmsg("On processing lineament Analyzer..........")
av.setstatus((recordCount / theftab.getselection.count) * 100)
SelectedShape = theftab.returnvalue(shpfld,Selrec)
```

*7) The first "if statement" is for all the lineaments are within the circle, and the second "else statement" is for intersection between the circle and lineament exists*

```
if (SelectedShape.iscontainedin(theSRCShape)) then
  alineshp = SelectedShape
else
  alineshp = SelectedShape.LineIntersection(theSRCshape)
end
```

*8) Count the intersecting points of lineaments within each circle*

```
    for each rn in thetab.getselection
      if (selrec <> rn) then
        yhsline = thetab.returnvalue(shpfld, rn)
        if (yhsline.iscontainedin(theSRCShape)) then
          yhsline = yhsline
        else
          yhsline = yhsline.LineIntersection(theSRCshape)
        end
        if (alineshp.intersects(yhsline)) then
          intersectnum = intersectnum + 1
        end
      end
end
```

Fig. 7. The main code and description of PL-DENS script file.

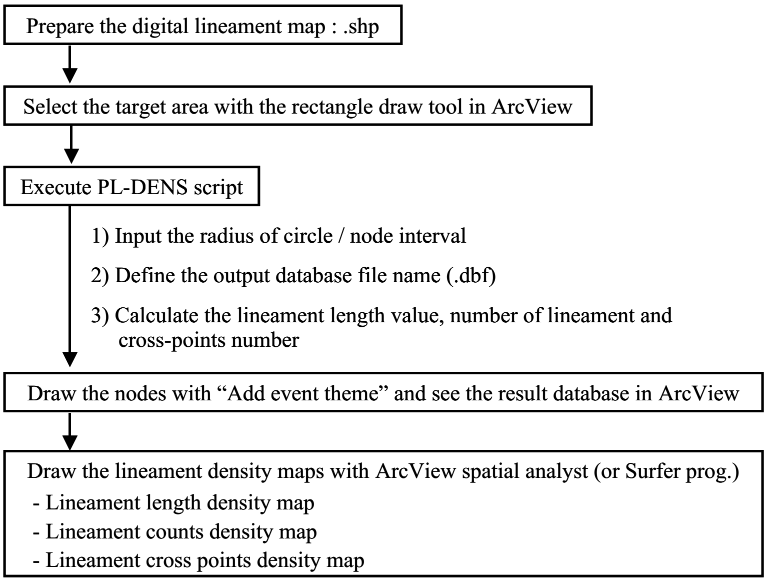



Fig 8. The schematic flow chart for the lineament density map using PL-DENS Script and ArcView spatial analyst.

Table 4. Basic table structure and an example of an output file produced by PL-DENS script

| Shape | ID | X-Coord | Y-Coord | LEN-SUM | LEN-DENS | CNT-SUM | CNT-DENS | INTER-SECT | INTER-DENS | 90 ~80 | 80 ~70 | .... | -70 ~-80 | -80 ~-90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | 1 | 141136.4 | 125923.4 | 435.09 | 0.02 | 1 | 0.04 | 0 | 0.00 | 0 | 0 | .... | 1 | 0 |
| Point | 2 | 141136.4 | 128923.4 | 909.34 | 0.03 | 2 | 0.07 | 1 | 0.04 | 1 | 0 | .... | 0 | 1 |
| .... | ... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Point | 252 | 192136.4 | 164923.4 | 1099.03 | 0.04 | 3 | 0.11 | 1 | 0.04 | 0 | 2 | .... | 0 | 0 |

a) Youngam district b) Kangjin district

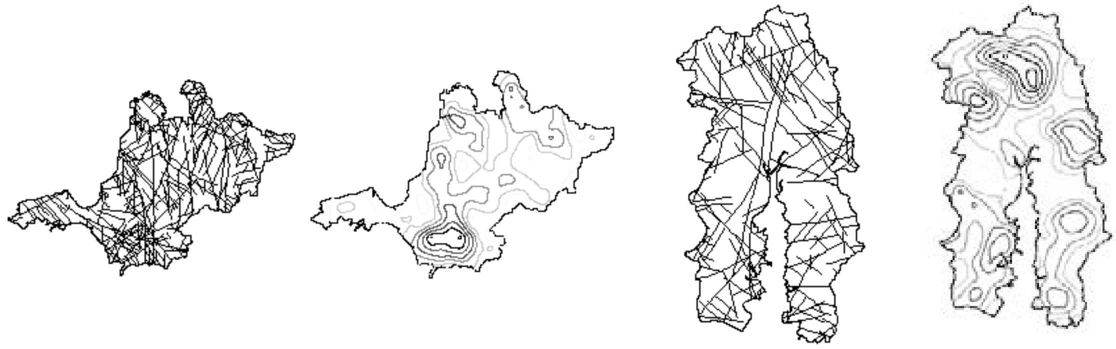


Fig. 9. Example of a lineament length density map made using PL-DENS script for 2 districts (darker lines are higher density of lineament length).

*5.4. Distance from well to lineament: Dist-to-Line*

To reveal the relation between groundwater productivity and the lineament, a priority is given to investigate the relation between the existing wells and lineament. This "Dist-to-Line" script can be used for calculating the distance from a well to the nearest lineament. If well location or well productivity is related to the lineament, the distance from a well to lineament can become important in studying the lineament characteristics. Fig 10 and Table 5 show the main code of this script and the table structure of an output file, respectively. The results of "Dist-to-Line" calculations are stored in the table of wells by adding the "distance to line" field as the last column of the table. Based on these results, we can calculate the linear relation between well location and lineament with a linear regression model or with other statistic calculations. We can also draw a distribution map of the distance from well to lineament, which can be used in analyzing the relation between wells and lineaments.

*1) Calculate the distance from each well to the nearest lineament*

```
for each r1 in theAllRecords
  point = pointFtab.ReturnValue(shapefield, r1)
  mindist = 99999999
  dist = 0
  for each i in 1..100
    mycircle = Circle.Make(point, i*500)
    lineFtab.SelectByShapes(mycircle, #VTAB_SELTYPE_NEW )
    for each r2 in lineFtab.GetSelection
      line = lineFtab.ReturnValue(shapefield, r2)
      dist = point.Distance(line)
      if (mindist > dist) then
```

```
      mindist = dist
    end
  end
 end
end
```

Fig 10. The main code and description of Dist-to-Line script file.

Table 5 Basic table structure and an example of an output file produced by the Dist-to-Line script

| Shape | Well No. | ...... | Distance to line (m) |
|---|---|---|---|
| Point | YAW001 | ...... | 225.13 |
| Point | YAW002 | ...... | 301.03 |
| .... | .... | ...... | .... |
| Point | YAW110 | ...... | 93.88 |

### *5.5. Distance from well to lineament cross-points: Dist-to-Crosspoint*

To investigate the relation between the lineament and groundwater occurrence, it is necessary to examine the productivity of wells near the cross points of lineaments. The cross points of lineaments are important in groundwater flow and recharge. Fig 11 and Table 6 show the main code of this script and the table structure of an output file, respectively. The result calculated by "Dist-to-Crosspoint" is stored in the table of wells by adding the "distance to line" field at the last column of the table. Also, the data table for cross point location is produced by this script and the location map of lineament cross points can be drawn using "Add event theme" menu in ArcView. Base on these results, we can analyze the relation between well location or productivity and the cross points of lineaments.

*1) Extract the cross points for linearments and make the shape file*

```
for each x in leftxcood..rightxcoord by gridsize
  for each y in bottomycoord..topycoord by gridsize
    selRect = Rect.MakeXY(x, y, x+gridsize, y+gridsize)
    thetheme.SelectbyShapes(selRect, #VTAB_SELTYPE_NEW)
    for each line in thetheme.GetSelection
      ptlist = l.PointIntersection(ll)
      for each newPt in ptlist
        newrecordnum = crossPointFtab.AddRecord
        crossPointFtab.SetValue(shapefield, newrecordnum, newPt)
      end
    end
  end
end
```

*2) Calculate the distance from lineament cross point to the nearest well point*

```
for each r1 in theAllRecords
```

```
wellpoint = wellpointFtab.ReturnValue(shapefield, r1)
mindist = 99999999
dist = 0
for each i in 1..100
  mycircle = Circle.Make(wellpoint, i*500)
  crossPointFtab.SelectByShapes(mycircle, #VTAB_SELTYPE_NEW )
  for each r2 in crossPointFtab.GetSelection
    crossPoint = crossPointFtab.ReturnValue(shapefield, r2)
    dist = crossPoint.Distance(wellpoint)
    if (mindist > dist) then
      mindist = dist
    end
  end
end
end
```

Fig 11. The main code and description of the Dist-to-Crosspoint script file.

Table 6. Basic table structure and an example of an output file produced by the Dist-to-Crosspoint script

| Shape | Well No. | ...... | Distance to cross point (m) |
|---|---|---|---|
| Point | YAW001 | ...... | 320.22 |
| Point | YAW002 | ...... | 80.78 |
| .... | .... | ...... | .... |
| Point | YAW110 | ...... | 128.51 |

## 6. Summary and discussions

Lineament maps such as lineament density map are important to reveal the groundwater recharge, flow and development. Especially, groundwater flows and yields in mountainous areas composed of crystalline rocks with many fractures and faults are governed mainly by the lineaments comprised of fractures, joints and faults. Furthermore, the distribution of lineaments is closely related to well productivity or yield. That is to say, these lineaments may give important information on the distribution of well development and management. Therefore, the lineament and related maps are considered as essential maps in basic groundwater surveys in Korea.

In this study, we developed the two Avenue™ scripts, "Remove-node" and "Generalize", for optimizing the original lineament map and the five Avenue™ scripts, "L-STAT", "PL-DENS", "L-Selection", "Dist-to-Line" and "Dist-to-Crosspoint", for analyzing the lineaments and calculating the lineament density values.

The first two scripts were very useful for creating a basic optimized lineament map from original digitized lineament map, and with this optimized lineament map we can calculate the statistics for lineaments and the density for length, counts and cross points with "PL-DENS" and other scripts. Especially if we want to investigate the relationship between the extensional fractures and groundwater productivity or well yield, we can use the "L-Selection" script to extract some lineaments with a specific direction.

Hydraulic properties of the geological media near and around the lineaments can't be determined using only raw remote sensing data, and thus well yield capacity can't be directly estimated by lineaments' characteristics. So they need to be analyzed with the investigated results at the field. Groundwater characteristics are generally spatially variable. The supposition is that lineaments are closely related to the occurrence of the groundwater resources. The developments and water supply are importantly dependent on the availability of groundwater.

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*Author Information :*

Gyoo-Bum Kim

Vice chief of groundwater investigation section
Investigation and Planning Department
Korea Water Resources Corporation
San 6-2, Yonchuk-dong, Daeduk-gu
Daejon city, South Korea

Fax : +82-42-629-2749
Tel : +82-42-629-2726
E-mail : gbkim@kowaco.or.kr